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Helena Hepola

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Rearing strategies of young dairy calves in relation to production, behaviour and welfare

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Academic dissertation

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Abstract

Individual housing, deprivation of sucking behaviour, and low milk intake are considered to be some of the factors which may reduce calf welfare. This thesis consists of three experiments that examined the effects of various rearing strategies on feed intake, growth, oral behaviour, and welfare of young dairy calves. Results concerning group (outside or inside the barn) and individual rearing of calves, keeping cows and calves together for a longer period than colostrum feeding, and water drinking on *ad libitum* milk replacer feeding are presented. In addition, meta-analyses from the three above mentioned experiments were conducted to evaluate relationships between intakes of different feeds, and feed intake and growth before and after weaning off milk.

The aim of the first experiment was to compare feeding behaviour and the performance of young dairy calves in warm and cold group housing systems. In addition, housing calves individually and in groups inside the barn was compared. Group rearing may socially facilitate calves to start eating dry feeds and ruminating earlier than individual housing. Cross sucking problems in calf groups can be reduced by feeding and management factors. Group-housed calves can cope with the changing temperatures in an unheated production system if they are under careful management. Low temperatures can, however, decrease the time spent eating, and may thus affect growth, at least if the eating place is outside, and separated from the lying area which is in shelter.

In the second experiment the effect of five weeks of restricted suckling (twice a day suckling two hours after the cows were milked) followed by three weeks of even more restricted suckling (once a day) was compared to abrupt weaning after five weeks of restricted suckling to see if the former had less effect on feed intake, growth and weaning behaviour of the calves. When the calves were weaned at five weeks of age, they did not eat dry feed in sufficient amounts to compensate for the loss of milk provision. Consequently, the calves abruptly weaned at the age of five weeks lost weight after weaning. Therefore, from a calf welfare point of view total weaning at the age of five weeks from high milk allowance is not recommended since calves had difficulties in coping in that situation. Five weeks of twice a day suckling, followed by three weeks of once a day suckling reduces the decline in energy intake and growth following weaning. However, weaning from suckling the dam affected calves' behaviour, both at the age of five and eight weeks, by increasing calves' restlessness and vocalizations after weaning.

In the third experiment the objective was firstly to examine water intake of calves fed acidified milk replacer *ad libitum* during the milk feeding and weaning stages. Secondly, the objective was to determine whether the method of water delivery (open bucket or nipple) impacted water and feed intake and growth during these periods, or oral behaviour during weaning. Calves consumed very little water when they had *ad libitum* access to acidified milk replacer, but after weaning the calves increased their water intake very quickly. No differences in water intake between the two water sources were noted

either before or after abrupt weaning. Calves did, however, have some difficulties in using water nipples, which appeared as atypical drinking behaviours.

Meta-analysis indicated that concentrate and hay intakes decreased by increased milk intake during the final part of the milk feeding period. Milk intake at the age of 2-5 and 6-8 weeks clearly increased growth, more at the age of 2-5 weeks than at the age of 6-8 weeks. There was a positive relationship between concentrate intake before and after weaning. In addition, a positive relationship was found between water and concentrate intake after weaning.

Results from feed intake and growth data does not always reveal the possible differences in rearing systems for young dairy calves in terms of animal welfare as was seen in these experiments. Therefore, behaviour should also be taken into account when comparing rearing strategies for dairy calves.

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List of original publications

This thesis is based on the following articles referred to in the text by their Roman numerals.

I Hänninen, L., Hepola, H., Rushen, J., de Passillé, A.M., Pursiainen, P., Tuure, V.-M., Syrjälä-Qvist, L., Pyykkönen, M. & Saloniemi, H. 2003. Resting behaviour, growth and diarrhoea incidence rate of young dairy calves housed individually or in groups in warm or cold buildings. Acta Agriculturae Scandinavica, Section A. Animal Science 53:21-28.

II Hepola. H., Hänninen, L., Pursiainen, P., Tuure, V-M., Syrjälä-Qvist, L., Pyykkönen, M. & Saloniemi, H. 2006. Feed intake and oral behaviour of dairy calves housed individually or in groups in warm or cold buildings. Livestock Science 105:94-104.

III Hepola, H., Raussi, S., Veissier, I., Pursiainen, P., Ikkeläjärvi, K., Saloniemi, H. & Syrjälä-Qvist, L. 2008. Five or eight weeks of restricted suckling: influence on dairy calves' feed intake, growth and suckling behaviour. Acta Agriculturae Scandinavica, Section A. Animal Science. In press.

IV Hepola, H., Hänninen, L., Raussi, S., Pursiainen, P., Aarnikoivu, A. & Saloniemi, H. 2008. Effects of providing water from a bucket or a nipple on the performance and behavior of calves fed ad libitum volumes of acidified milk replacer. Journal of Dairy Science 91:1486-1496.

The author planned all the experiments together with her co-authors and also participated as one of the responsible researchers in conducting the experiments. The author participated in the data analysis and writing of the publication I. The author was responsible for calculation of the results, statistical analysis, and preparation of the manuscripts II to IV.

Contents

1 Introduction

In the future calves should be high producing dairy cows or fast-growing beef animals. However, the rearing of calves still needs more attention in many farms (Evira 2006). Farm size in Finland is increasing which also presents a challenge when rearing calves successfully. Milk amount and milk feeding methods can affect calves' dry feed intake, growth and health, and also their behaviour and welfare. Individual housing, deprivation of sucking behaviour, and low milk intake are considered to be some of the factors which may reduce calf welfare (de Passillé and Rushen 2006a).

It is possible to rear calves in various ways, and recommendations for milk amount and weaning time differ between countries. Traditionally the calves are fed limited amounts of milk, the common daily recommendations being e.g. 8-10 % of body weight (Drackley 2005) or 500 g milk powder per day per calf (Wicks et al. 2005), and are encouraged to start eating dry feeds at an early age. In many countries calves are weaned early, and this method is justified with cheaper feeding costs, less labour, and healthier animals. In Finland the recommendation for milk allowance of dairy calves varies from 6 to 8 litres per day until *ad libitum* and the calves are usually weaned off milk at the age of eight weeks (e.g. Kemppi 2005, Mäntysaari 2007), except on organic farms where calves must have milk until three months of age (Evira 2007). It is also recommended to reduce milk amount during 1-2 weeks before weaning off milk (e.g. Kemppi 2005, Mäntysaari 2007). In the United States dairy calves are commonly fed milk twice daily and weaned at the age of 8.4 weeks, but 30 % of farms wean calves at 6 weeks of age or less (Kehoe et al. 2007). In Spain the calves are usually fed 4 l/day and are weaned at the age of 60 days (Terré et al. 2006a). Danish recommendation for milk allowance is 4.8 l/day for heavy breeds and 60 % of this amount for Jersey as referred to by Jensen (2006). In Switzerland the typical weaning time is longer than in many other countries up to 12-31 weeks (Keil and Langhans 2001). Concerns about animal welfare and behavioural needs of animals have increased the desire to find out new ways to rear dairy calves.

In free ranging and feral herds of cattle, the calf suckles its dam for 8-12 months as reviewed by Jonasen and Krohn (1991). Newborn calves suckle 5 to 8 times per day and older calves 3 to 5 times per day. Each suckling bout lasts about 10-15 minutes (Phillips 2002). Dairy calves are separated from their dams very soon after birth and are often fed restricted amount of milk twice a day from open buckets. Milk induces a sucking motivation (de Passillé et al. 1992) and if the calves are not allowed to suck a teat, they can perform a lot of non-nutritive sucking e.g. they suck pen structures, or if they are in groups, other calves which is called cross-sucking (Jensen 2003, de Passillé and Rushen 2006a). Cross-sucking can lead to inter-sucking i.e. sucking between heifers and cows (Keil et al. 2000, Keil and Langhans 2001, Lidfors and Isberg 2003). Calves are more active when they are together with their dam for some days (Jonasen and Krohn 1991), and individually housed calves sleep more fragmentarily than dam-reared calves (Hänninen et al. 2007). Some farmers allow the calves to suckle freely their dams for several weeks (Lidfors and Berg 2004), although it is not a common practice to keep

dairy cows and calves together longer than the colostrum period. Restricted suckling consists of letting the calf suckle its dam or another cow for some time after the cow is milked. This practice has been used in the tropics. Zebu cows usually require the presence of their calf for milk let down (Das et al. 2000). However, there is concern about stress after separation when the bond between the dam and the calf is established. In many experiments separation has resulted in behavioural reactions on both sides and impaired performance of the calf (Jonasen and Krohn 1991, Lidfors 1996, Flower and Weary 2001). On the other hand, weaning at two stages, first from milk, and then from dam, has given good results when weaning beef calves (Haley et al. 2005) or foster cows (Loberg et al. 2007). Results of restricted suckling of dairy cows are few (Jonasen and Krohn 1991, de Passillé et al. 1997, Fröberg et al. 2005) and more results are needed, especially about behaviour after weaning.

During the last few years there has been a lot of research into more intensive milk feeding (e.g. Diaz et al. 2001). Calves grow more with increased milk intake (Jasper and Weary 2002, Härtel et al. 2002, Jensen 2006, Huuskonen and Khalili 2007) and they might benefit also later in life from a greater amount of milk during the milk-feeding period (e.g. reviews by Tanan and Newbold 2002, Drackley 2005). However, not many long term experiments have been done. In two Danish experiments (Foldager and Krohn 1994, Foldager et al. 1997) milk production in the first lactation was higher for calves which had received greater amounts of milk during the milk feeding periods than for calves which were fed about 4.5 kg of milk per day. Increased milk intake during the pre-weaning period affected body weight, decreased age of puberty onset, and increased milk yield at first lactation, but did not affect skeletal size of the adult animal in the experiment by Shamay et al. (2005). Increased milk production during the first lactation, and calving 30 days earlier, was also seen by Bar-Peled et al. (1997) when comparing cows which had been suckling their dams three times per day or fed restrictively during milk feeding periods. In addition, the increases in relative body weight and wither height are the most rapid and cost efficient during the first 6 months of age (Kertz et al. 1998). Also, nutritional status can benefit the immune system function and decrease mortality (Drackley 2005). It has been recommended that a higher milk allowance be offered for calves fed by automatic milk-feeders because the calves are more satiated and the feeder occupancy is lower (Jensen and Holm 2003). Increased number of unrewarded visits to the feeder (Hammon et al. 2002, de Paula Vieira et al. 2008), more competition at the feeder and duration of nutritive sucking bouts (de Paula Vieira et al. 2008) can be signs of hunger with milk feeder fed calves. *Ad libitum* acidified milk feeding has increased in Finland, especially in specialized beef rearing units. One main benefit of acidification is its preservative effect. When 3 ml 85 % formic acid is added in 1 litre of drink, the pH of the drink is 4.0-4.5 and milk or milk replacer can be stored for up to 3 days. When the drink is made for some days at one time, the labour demand is smaller (Bothmer 1992). One disadvantage of *ad libitum* feeding is the economic feasibility of this system compared to the restricted feeding because the milk amounts drunk are big (Swannack 1983, Nocek and Braund 1986). Therefore practical recommendations to decrease milk amount to 7-8 litres per calf per day have also been presented for calves reared for beef

production in Finland (Jokinen 2007). There is, however, little information available on dairy calves' water drinking on *ad libitum* milk feeding or on calves' behaviour after weaning from an *ad libitum* milk allowance.

According to the EU legislation (Commission Decision 97/182/EC) the calves must have water all the time when they are ill or when the weather is hot. However, water is important also for the healthy animals. Water is essential in many biochemical processes in the body, having a role in regulation of body temperature and osmotic pressure (Davis and Drackley 1998). Calves receive water from milk, from other feeds, and from free water. Water is also gained in the oxidation of food and body tissues. It is possible that *ad libitum* fed calves don't consume water because they will get enough liquid from *ad libitum* milk replacer. On the other hand, rumen microbes live in moist environment (Yokoyama and Johnson 1988) and water from milk or milk replacer goes directly to the abomasum and not to the rumen (Ørskov 1972). Provision of water affected the development of rumen papillae of veal calves receiving straw (Gottardo et al. 2002). Adult cows prefer to use larger troughs instead of smaller ones as a water source (Machado et al. 2004, Teixeira et al. 2006). Water nipples might be better because of the hygienic reasons for young stock, but there is no information about usage or preferences of different water sources for calves.

Cattle are gregarious animals and therefore rearing together with conspesifics satisfies their need for social behaviour. Social behaviour includes cohesive behaviour, such as social grooming (licking others) and agonistic behaviour including aggression and submission (Bouissou et al. 2001). Group rearing also usually allows more space and fulfils calves' need for exploration, locomotion (Phillips 2002) and play (Jensen et al. 1998) and does not restrict calves' sleeping postures (de Wilt 1985). This has been taken into account in the European Union's legislation (Council Directive 97/2/EC) so that the calves between eight weeks and six months of age are not allowed to be in individual pens or tethered but must be reared in groups. In Finland, the number of calves less than eight weeks of age reared in groups is also increasing, especially in beef production. Group-housing may also stimulate feed consumption (Warnick et al. 1977, Richard et al. 1988) by social facilitation (Fraser and Broom 1990). Moreover, low building costs increased the interest in housing calves in cold conditions some years ago. Calves can tolerate relatively low temperatures, the lower critical temperature (LCT) of dairy calves being about 8-10 ^{o}C from 3 to 56 days of age (Webster et al. 1978). In some studies the calves´ feed intake in cold housing has been higher (McKnight 1978, Kunz and Montandon 1983) than in warm housing. Controversial results exist of the temperature effects on growth (Jorgenson et al. 1970, Hansen 1984, Scibilia et al. 1987, Scott et al. 1993, Kauppinen 2000). Group rearing of dairy calves and feed intake connected with oral behaviour has not been widely studied in a changing climate below 0 ^{o}C.

Animal welfare can be defined in various ways (Appleby and Hughes 1997). Knowledge about behaviour, health and physiology of animals is essential when defining animal welfare. In this thesis welfare is defined as calf's state as regards its capacity to cope in

the environment. Both failure to cope with the environment and difficulty in coping are indicators of poor welfare (Broom 1991, 1996). In this thesis calves' growth rate, feed intake and oral behaviour are used as measures of coping. Failures to cope are examined as impaired growth rate, decreased feed intake and live weight, as well as changes in calves' behaviour. Regulations on the protection of animals provide minimum standards how to keep animals. It is now possible to pay animal welfare support if minimum standards are exceeded in some European countries (Koikkalainen and Miettinen 2008).

Overall, the objective of this thesis is to focus on both production and behavioural aspects of different rearing conditions, especially on the effects of different milk feeding systems on a calf's performance, behaviour and welfare. Results on group (outside or inside the barn) and individual rearing of calves, keeping cows and calves together for a longer period than colostrum feeding, and the water intake and different water sources (open bucket or nipple) of *ad libitum* acidified milk replacer fed calves are presented in this study. In addition, meta-analyses were conducted to evaluate relationships between intakes of different feeds, and feed intake and growth before and after weaning off milk.

2 Materials and methods

Data for this thesis are from three experiments that were performed at the Viikki Experimental Farm of the University of Helsinki. The experimental procedures were approved by the Ethical committees for the use of Experimental Animals at the University of Helsinki. Experimental procedures are described in detail in publications I-IV. A short summary is presented here.

2.1 Animals, diets, and experimental designs

In the first experiment (I-II) the influence of environmental temperature, housing, social company and age on the feed intake, growth, and oral behaviours of calves was studied. Male Ayrshire (Ay) and Holstein Friesian (Fr) dairy calves were housed for seven weeks individually (INDIV) or 11 weeks in groups of four; indoors (INGROUP) or outdoors either with (OUTWARM) or without a heated shelter (OUTCOLD). During the 7 week milk feeding period the calves received 2 L of whole milk from individual teat buckets three times per day. Data were collected on 12 INDIV calves and on 17 groups of four calves (six OUTWARM groups, six OUTCOLD groups and five INGROUP groups) during different seasons in 1996-1999.

The second experiment (III) was performed in 1998-1999. In this experiment the effect of restricted suckling on the feed intake, growth, and behaviour during weaning of dairy calves (Ay, both male and female) was studied. Six calves suckled their dams twice a day for five weeks two hours after morning milking (at about 07:00) and evening milking (at about 18:00) then once a day for three weeks (DAM8). Six calves (DAM5) suckled during five weeks in the same way as calves in DAM8 and were then abruptly weaned. Six calves (TEAT8) were fed milk from teat buckets and received the same amount of whole milk than DAM8. The feed intake and the growth of all calves were measured up to the age of 12 weeks.

The third experiment was performed in 2004-2005 (IV). In this experiment the water intake of *ad libitum* acidified milk replacer fed calves was examined during the milk feeding and weaning stages. In addition, the method of water delivery (open bucket or nipple) was studied to see if this had any effect on water and feed intake and growth during these periods or oral behaviour during weaning. Twenty-four calves (Ay/Fr, both male and female) were paired according to their birth date, and each allotted to one of the water source treatments; an open bucket (WATERBUCKET) or a water nipple (WATERNIPPLE). The experiment began for the pair of calves when the youngest calf in the pair was 7 days old and the oldest one a maximum of 11 days old. The experiment lasted for 9 weeks.

A summary of the experiments is presented in Table 1.

Table 1. *The summary of the experiments.*

Experiment (Paper)	*Number of calves*	*Age of calves, weeks*	*Treatments*	*Abbreviation*
1 (I-II)	24	1-12	Group pen outside with heated shelter, 6 l milk/day	OUTWARM
	24	1-12	Group pen outside with unheated shelter, 6 l milk/day	OUTCOLD
	20	1-12	Group pen inside, 6 l milk/day	INGROUP
	12	1-8	Individual pens, 6 l milk/day	INDIV
2 (III)	6	0-12	Calf suckling dam restrictively 8 weeks	DAM8
	6	0-12	Calf suckling dam restrictively 5 weeks	DAM5
	6	0-12	Milk from teat buckets 8 weeks, amount matched with DAM8 and DAM5	TEAT8
3 (IV)	12	1-10	Individual pen + yard with pair, milk replacer *ad libitum*, water from buckets	WATERBUCKET
	12	1-10	Individual pen + yard with pair, milk replacer *ad libitum*, water from nipple	WATERNIPPLE

2.2 Housing

In the first experiment (I, II) the calves were housed either individually (INDIV), or in groups of four, in one of the three group-housing systems: one indoors (INGROUP) and two outdoors (OUTCOLD or OUTWARM). The three group housing systems were identical in structure and area (Figure 1). They comprised a straw-bedded shelter and a bark-bedded yard area. The shelter in the OUTCOLD housing was unheated but windproof. The temperature ranges for the different experimental groups are presented in Papers I and II. The individual pens were 1.0 x 1.2 m and had wooden-slatted floors and solid plywood walls above which the calves could have some visual and body contact with their neighbours.

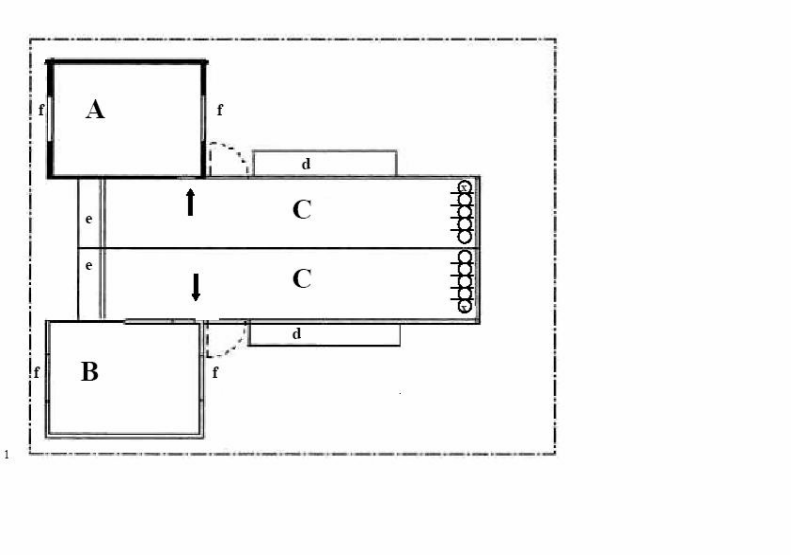

Figure 1. *Diagram of the group pen structure of four calves. A:OUTWARM: 3 x 4 m straw-bedded, heated shelter, daily temperature (mean ±SD) +11±6 ^{o}C; B:OUTCOLD: 3 x 4 m straw-bedded unheated shelter, windproof, daily temperature +3±2 ^{o}C higher than the yard outside; C: 2 x 10 m bark-bedded, roof-covered outside yard; d: hay trough; e: concentrate trough; f: window; ○:teat bucket; ⊗: heated water bowl (unheated for INGROUP); →:plastic strip door; __. :roof-covered area. The INGROUP housing system was identical in structure to the other two systems.*

In the second experiment (III) the calves were in individual pens (1.0 m x 1.2 m) with wooden slatted floors and an open upper part so that they could see and touch each other. The calf pens and tie stalls (1.7 m x 1.35 m) for cows were in the same barn. At eight weeks of age, the calves were moved to another building where they were placed in individual pens with a solid concrete floor (1.2 x 1.2 m), straw bedding and solid plywood walls. Also here the calves could see and hear each other.

In the third experiment (IV) the calves were housed individually in 1.2 m x 1.5 m solid-floor pens bedded with a turf-sawdust mixture. The calves could have some body contact with neighbouring calves over the 93-cm-high pen walls. A 20 cm x 45 cm hole in the back wall of the pen permitted additional contact between a calf-pair. Moreover, every day from 9:00 to 11:00 a.m., when the pens were cleaned, the calf-pair was released to a separate yard (1.2 x 3.0 m) with solid partitions between yards (107 cm high). The yard was littered with wood-shavings, but no feed or water was offered.

2.3 Feeds and measurements of feed intake and growth, and feed analysis

Whole milk (I-II) and whole milk/milk-replacer (IV) intakes were measured daily during experimental weeks 1-7. The intake of milk by suckled calves (DAM5 and DAM8) was measured by weighing the calves before and after suckling (III). This was done three times a week during the first two weeks, and twice a week thereafter during weeks 3-8. Diapers (used for adult patients) fixed with masking tape were used to prevent weight losses due to defecation or urination between the two weighings. The amount of milk provided to teat fed calves (TEAT8) was calculated according to how much the calves in suckling groups received milk.

In I-II the calves received a barley-oats mixture (1:1, including 3.85 % minerals), with 12.3 MJ metabolizable energy (ME) and 122 g crude protein (CP)/kg dry matter (DM) during the milk feeding period. After weaning, the concentrate (12.3 MJ ME and 161 g CP/kg DM) consisted of 85 % barley-oats mixture (1:1, including 3.85% minerals) and 15 % rape seed meal. In III the calves were offered a barley-oats-mixture (1:1, including 3.75 % minerals, 12.3 MJ ME and 136 g CP/kg DM) during the milk feeding period. After weaning, protein concentrate, containing soya bean meal and rapeseed meal (Tiiviste-Maituri, Raisio, Finland, 12.8 MJ ME and 280 g CP /kg DM) was added to the concentrate mixture according to the time schedule described in detail in paper III. In IV the calves were offered a commercial concentrate mixture (Primo Start, Suomen Rehu, Finland, 13 MJ ME and 196 g CP/kg DM) during the whole experiment. In all experiments the concentrates were available *ad libitum* during the milk feeding period but after weaning off milk the concentrate amount was restricted to a maximum of 2.5 (I-III) or 3 (IV) kg per calf per day.

All the calves (I-IV) had hay available *ad libitum* throughout the experiments. The quality of hay varied between experiments: 8.0 MJ ME, 101 g CP and 668 g neutral detergent fibre (NDF) / kg DM (I-II), 8.3 MJ ME, 124 g CP and 634 g NDF / kg DM (III), and 10.6 MJ ME, 146 g CP and 543 g NDF / kg DM (IV). Hay was chosen as roughage for these experiments, because the quality of hay is easier to control than quality of silage during the experiment.

Concentrate and hay intakes were measured on a weekly basis starting either in the beginning of the experiment (I-III) or from the fourth experimental week (IV). In addition in IV the concentrate intake was measured daily during experimental week eight i.e. after weaning off milk.

Milk was analyzed (I-IV) for fat, protein, and lactose with infrared analysis (MilkoScan FT6000). The chemical composition of milk replacer, concentrate, and hay samples were analyzed using the AOAC (1995) method 942.05 for ash, method 920.39 for ether extract (after HCl hydrolysis), and method 984.13 for crude protein analyses. Neutral detergent fibre (NDF) was analyzed according to Van Soest et al. (1991). Energy (MJ ME) and protein (AAT= amino acids absorbable from the small intestine) values of feeds were calculated according to Finnish feed tables (MTT 2006). Feed efficiency was calculated as weight gain divided by DM intake or ME intake.

Water was offered *ad libitum* in all experiments. Water intake was not measured in I-III. In IV water was offered either from an open bucket or from a water nipple. Water intake was measured daily throughout the experiment. Water intake data were missing for one WATERNIPPLE calf before weaning.

In I-II calves were weighed once a week during the experiment, on two consecutive days at the beginning and at the end of the experiment. In III the calves were weighed once a week during the milk feeding period and every second week thereafter, on two consecutive days at the beginning and end of the experiment. In IV the calves were weighed once a week during the milk feeding period, daily during week 8, and again once during week 9. The calves were weighed on two consecutive days in the beginning, during weaning and at the end of the experiment.

2.4 Behaviour observations

In II the oral behaviour of the calves was studied by direct observation of 11 h per week. Observation periods (06.00-09.00, 13.00-16.00, 19.00-22.00, 22.00-24.00) were randomly allocated over four observation days per week (Tuesday to Friday), with one observation time period per day during each experimental week. Observations were made on experimental weeks 1, 3, 5, 7, 10 and 12 for the group-housed calves (INGROUP, OUTCOLD, OUTWARM), and during experimental weeks 1, 3, 5 and 7 for INDIV calves. During each observation period, recordings were made at 2 min intervals and the results are presented as a percentage of total observations. Furthermore, for this summary the results are calculated as min per day.

In III the duration of nursing and sucking (DAM8 and DAM5) was recorded using a stop-watch during morning nursing twice a week for the first two weeks and once a week thereafter. At the same time the frequency of teat changing was also observed.

In IV calves' oral behaviour was observed in two ways. Eating, drinking, ruminating, and vocalization where observed continuously from 24-h video tapes, filmed with a 12 h mode. The filming was done over five days; one day prior to weaning, at weaning, one day, two days, and one week after weaning. Bout frequency, mean bout duration, and total daily duration of all behaviours were measured. A milk-drinking bout was defined to have commenced when a calf took the teat of the bucket in its mouth. The milk-drinking bout ended when the calf started some other oral behaviour or did nothing with its mouth. Milk-drinking bouts were merged when the difference between the two consecutive bouts was less than 60 s and the calf did nothing with its mouth during that interval. Definitions of water drinking and eating bouts are defined in paper IV. Licking, sucking and tongue rolling were registered by direct observation two days before and one day after the weaning when the calves were in the yard from 09:00 to 11:00. The results are presented as a percentage of observation time. These data were available from 22 calves, due to technical problems with one calf-pair recording.

The definitions of observed oral behaviours are presented in Table 2.

Table 2. *The definitions of observed behaviours.*

Behaviour	***Definition***
Eating behaviour	
Eating hay	*calf having hay in its mouth or head in the hay trough*
Eating concentrate	*calf having concentrate in its mouth or head in the concentrate trough*
Eating straw	*calf having straw in its mouth*
Eating bark	*calf having bark in its mouth*
Ruminating	*repetitive movements of lower jaw in the lateral plane*
Milk sucking behaviour	
Nursing	*the time that passed when the calf started to suck its dam and when it stopped sucking completely (had not been sucking for 1 min or started to lie down or left the dam and went to the alley or turned to another cow), all breaks were included in the nursing time*
Sucking	*the time when the calf had a teat in its mouth*
Teat changing	*the calf left the teat it was sucking and started to suck another teat*
Other oral behaviours	
Licking itself	*calf licking any part of itself*
Licking penmate	*calf's tongue touching any part of another calf*
Licking structures	*calf's tongue touching any part of pen structures or teat buckets*
Biting structures	*calf holding any part of the pen structures between jaws*
Sucking teat	*calf sucking a teat of the bucket*
Cross-sucking	*calf sucking any part of another calf*
Tongue rolling	*calf rolling its tongue in a repetitive way outside the mouth*
Vocalization	*calf keeping its head stretched upwards and mouth open*

2.5 Calculation and statistical analysis

A pen was considered as an experimental unit when the calves where reared in groups (I-II), otherwise an animal was an experimental unit (III-IV). A detailed description of the statistical methods is presented in attached papers I-IV. In brief, summary of the methods is as follows:

In II behavioural data from the group housing treatments (INGROUP, OUTCOLD, OUTWARM) was converted to weekly group means for the final analyses. The individual calf data (INDIV) was used as weekly individual means. The behavioural data were transformed taking arcsine of the square-root before the statistical analyses to meet the assumption of a normal distribution of the data. The differences between INGROUP, OUTWARM and OUTCOLD or INGROUP and INDIV were compared using the mixed model, taking repeated measures into account. The fixed factors were housing, experimental week and housing x experimental week interaction. Variables "tongue rolling" and "cross-sucking" did not distribute normally and thus differences between INGROUP, OUTWARM and OUTCOLD treatments were tested by the non-parametric Kruskall Wallis test. Differences between INDIV and INGROUP were tested with the Mann-U-Whitney-test. The differences in the mean daily feed intake (II) and weight gain (I) between INGROUP, OUTWARM and OUTCOLD, or INGROUP and INDIV, were compared using ANOVA. For the analyses of temperature effect, the temperature data were converted to weekly mean outside temperature (TEMP). The effect of TEMP on the correlation between housing (OUTCOLD or OUTWARM) and the mean weekly feed intake, growth and oral behaviours was tested with a linear regression model.

In III the average feed intake and growth were calculated for each calf over weeks 1-5, weeks 6-8 and weeks 9-12. The data were then analysed with a mixed model, with animal as a random factor, treatment and period as fixed factors, and interaction between period and treatment. For the nursing, sucking, and teat changing data, average values over weeks 1-5 and weeks 6-8 were calculated for each calf sucking its dam. The differences between weeks 1-5 and weeks 6-8 were tested with the same model as above.

In IV results for the mean individual feed and water intake, as well as for the growth data, were calculated over two periods; 1) Before weaning: 1-7 weeks for milk and water intake and growth, 4-7 weeks for concentrate, hay, total dry matter, energy and protein intake, and feed efficiency, and 2) After weaning: 8-9 weeks for concentrate, hay, total dry matter, energy and protein intake, growth, and feed efficiency. Feed intake and growth data were analyzed with a mixed model, taking repeated measures into account. The fixed factors were treatment (WATERBUCKET or WATERNIPPLE), period (before and after weaning; 1-7 weeks or 4-7 weeks vs. 8-9 weeks), and treatment x period interaction. The pair (the pair consisted of two calves from different treatments) was the

random effect. The effect of weaning on calves' concentrate and water intake and live weight change during the 8th week and behavioural data before and after weaning off milk was tested with the same mixed model as above but day was the fixed factor instead of period. Data for cross-sucking was transformed taking arcsine of the square-root before the statistical analyses to meet the assumption of a normal distribution of the data. Even after transformation tongue rolling data were not normally distributed. Therefore, this data were analysed with Friedman's two-way nonparametric ANOVA separately before weaning and after weaning.

Individual data from I-IV (treatments INDIV, DAM8, DAM5, TEAT8, WATERBUCKET, and WATERNIPPLE) were used for the meta-analysis of the feed intake and growth data. Data were grouped for three time periods: 2-5 weeks of age, 6-8 weeks of age, and 9-10 weeks of age. The beginning of the first period was chosen to be 2 weeks of age because data collection in I-II and IV started from 2 weeks of age. The end for the first period was chosen to be 5 weeks of age since the calves in III were weaned or their milk feeding times were decreased from two to one at this age. The end for the second period was weaning time for all calves, except for DAM5, which was weaned at the age of five weeks, and the end for the third period was the age until the data were collected in IV. Relationships between intakes of different feeds, and feed intake and growth are presented in this thesis. Data from all periods for all parameters are not available in every experiment. The meta-analyses were conducted with a mixed model (St-Pierre 2001). The fixed effects of the linear model were the intercept and slope. Treatments nested within experiments were considered as a random effect. Random effect for slope was not included to the final model because estimated variance of the random slopes was nearly zero and not practically important. Regression curves are presented based on predicted values of dependent variables vs. independent variables. Adjusted individual observations are also plotted (St-Pierre 2001). In addition, relationships between some parameters in IV were analyzed with a linear regression model.

The results are expressed as means/ LS means ± standard error. Statistical analyses were conducted with SPSS 8.0 for Windows (SPSS, 1988) in I, with the SAS System for Windows version 8.2 (SAS institute Inc., 1999-2001) in II and III, and with the SAS System for Windows version 9.1. (SAS Institute Inc., 2002-2003) in IV.

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3 Results and discussion

3.1 Feed intake

3.1.1 Milk feeding

The digestive system of the calf is unique. At the time of birth rumen, reticulum, and omasum are present but undeveloped and non-functional. Milk/milk-replacer goes directly to the abomasum through the oesophageal groove and the digestion of feed is functionally similar to that of simple-stomached animals. Rumination begins gradually when the calf starts to eat dry feeds (Roy 1980, Heinrichs and Lesmeister 2005). The young calves are still dependent on milk/milk-replacer during the first 3-4 weeks. During that time a liquid diet formulation is important because calves are very limited in the nutrients they can digest (Davis and Drackley 1998).

Restricted milk feeding

In I-II the calves received whole milk 3*2 litres per day and usually drank all the milk given receiving on average 0.77 ± 0.01 kg milk DM/day during 2-8 live weeks (Table 3). During the first month these restrictively milk fed calves (I-II) received more milk on average than generally recommended, 8-10 % of body weight (Drackley 2005) or 500 g milk powder per day per calf (Wicks et al. 2005), but decreasingly in relation to live weight because the given amount was fixed to be 6 l/day (Table 4). As a comparison, when the given milk amount was 10 % of body weight in the experiment by Appleby et al. (2001) the milk intake increased from 4.2 to 5.1 kg/day during the first four live weeks.

Restricted suckling

In III the calves were suckling their dams restrictedly. Restricted suckling consists of letting the calf suckle its dam or another cow for some time around the milking. The daily milk amount suckled was 7.2 kg (0.91 ± 0.05 kg DM) during weeks 1-5 when calves suckled twice per day which is 13.8 % of body weight on average and more than in I-II (Table 4). During weeks 6-8 the calves suckled only once per day and the milk amount suckled was 5.4 kg (0.65 ± 0.01 kg DM), 7.5 % of body weight (Table 4). Teat-fed calves in the same study received approximately the same amount of milk as suckling calves (III). The suckled milk amounts during the first week were smaller than in the same kind of experiment by Jonasen and Krohn (1991) but at approximately the same level as reported by de Passillé et al. (1997) and Fröberg et al. (2005). During the first

five weeks milk amounts suckled in III were still smaller than that reported by Jonasen and Krohn (1991). The shorter interval between milking and suckling in III (2 h after milking) than in the latter experiment (5 h) may explain the difference. The calves learned fairly easily to suck their dams but the problem was that poor milk let down was observed with some cows (III). This problem is not unique (Krohn et al. 1990, Bar-Peled et al. 1995) and diminishes the practice of restricted suckling as such. On the other hand, Fröberg et al. (2005) noticed poor milk let down when trying restricted suckling before milking but not when restricted suckling was carried out after milking. Some farms have had good results when the calf has had the possibility to suckle its dam freely (Lidfors and Berg 2004).

Ad libitum milk feeding

In *ad libitum* systems, calves are allowed to drink milk or milk replacer without any restriction. In the cold acidified milk replacer feeding system, calves have *ad libitum* access to milk replacer acidified with organic acids (Roy 1980, Hepola 2003). When having *ad libitum* access to acidified milk-replacer (IV) calves drank on average 12.9 kg when receiving 1.37 ± 0.04 kg DM per day (Table 3). This agrees well with 1.2 kg DM per day during the first five live weeks in a previous study (Richard et al. 1988). Milk replacer intake in IV was 18.6 % of body weight at 2 to 8 weeks of age (Table 4), which is as much as with whole milk fed veal calves (Khouri and Pickering 1968). The intake declined progressively relative to live weight (Table 4) as in the experiment by Khouri and Pickering (1968). The a*d libitum* acidified milk replacer fed calves (IV) had a higher intake than those fed *ad libitum* in a previous experiment in small groups (Härtel et al. 2002) when the calves drank 9.6 kg acidified whole milk per day. Intake in IV was also higher than in individual pens elsewhere (Appleby et al. 2001, Jasper and Weary 2002). In those studies, the calves consumed 9 to 10 litres of whole milk at 4 to 5 weeks of age, whereas calves in IV drank 13 to 14 litres. One reason for the differences between the experiments could be that in all the previous experiments whole milk was fed while milk replacer was provided in IV. The energy content of milk is greater than that of milk-replacer.

Calves in IV were reared in individual pens and they did not have competition for feeds which could also have an effect on their high milk replacer intake. Competition in groups can decrease feed intake (von Keyserlingk et al. 2004). The differences might also be explained by different feeding methods. In the study of Appleby et al. (2001), the calves consumed their largest meals when new warm milk was provided. In IV the temperature of the milk was always the same. High milk intake in *ad libitum* feeding can also be explained by sucking motivation. Milk induces a sucking motivation (de Passillé et al. 1992), and calves may suck milk from the teat even when they are satiated (Hammell et al. 1988). In addition, the calves can quench their thirst by drinking milk.

Milk intake increased from 8.6 ± 0.6 kg per day in the 1st experimental week to 14.0 ± 0.7 kg per day in the 7th experimental week, when the calves were about 8 weeks old. Variation in milk intake during the whole milk feeding period between individual calves was great (8.1-16.6 kg/day), which has also been found by others (Appleby et al. 2001, Huuskonen and Khalili 2008).

Table 3. *Feed DM intake, growth, and feed efficiency of calves before weaning off milk in I-IV.*

Treatment [1]	*Exp.*	*Age, weeks*	*Milk, kg/d*	*Concentrate, kg/d*	*Hay, kg/d*	*Growth, kg/d*	*Growth, kg/kg DM*
OUTWARM	I-II	2-8	0.78	0.22	0.07	0.81	0.75
OUTCOLD	I-II	2-8	0.78	0.30	0.07	0.83	0.73
INGROUP	I-II	2-8	0.79	0.26	0.07	0.88	0.79
INDIV	I-II	2-8	0.74	0.20	0.04	0.76	0.77
DAM8	III	1-8	0.74	0.08	0.05	0.77	0.88
DAM5	III	1-8	0.61	0.30	0.06	0.81	0.82
		1-5	1.02	0.01	0.01	1.17	1.12
		6-8	-	0.75	0.17	0.34	0.37
TEAT8	III	1-8	0.80	0.15	0.05	0.75	0.74
WATERBUCKET[2]	IV	2-8	1.32	0.15	0.11	1.09	0.67
WATERNIPPLE [2]	IV	2-8	1.39	0.17	0.10	1.15	0.65

[1] Abbreviations are explained in Table 1 (page 6).

[2] 5-8 weeks for concentrate, hay, and growth kg / kg DM

Table 4. *Milk (I-III) or acidified milk replacer (IV) intake as % of the body weight in the beginning of each week.*

Treatment [1]	*Exp.*	*Age of calves in weeks*							
		1	2	3	4	5	6	7	8
OUTWARM	I-II		12.2	11.0	10.5	9.7	8.9	8.2	7.6
OUTCOLD	I-II		12.4	10.9	10.8	9.7	8.9	8.0	7.5
INGROUP	I-II		12.3	11.4	10.5	9.6	8.7	8.0	7.3
INDIV	I-II		12.2	11.4	10.8	9.7	9.2	8.5	7.6
DAM8	III	10.7	13.4	13.3	12.8	12.3	7.8	7.8	6.9
DAM5	III	17.8	17.2	14.1	13.7	12.2	-	-	-
TEAT8	III	13.6	13.6	13.6	12.5	12.6	6.6	6.2	5.8
WATERBUCKET	IV		16.8	21.4	20.8	19.6	18.0	17.2	14.9
WATERNIPPLE	IV		18.7	21.8	21.1	19.4	18.0	17.3	14.7

[1] Abbreviations are explained in Table 1 (page 6).

Table 5. *Feed DM intake, growth, and feed efficiency of calves after weaning off milk in I-IV.*

Treatment [1]	*Exp.*	*Age, weeks*	*Concentrate, kg/d*	*Hay, kg/d*	*Growth, kg/d*	*Growth, kg/kg DM*
OUTWARM	I-II	9-12	1.85	0.35	1.01	0.45
OUTCOLD	I-II	9-12	1.89	0.47	1.05	0.44
INGROUP	I-II	9-12	2.04	0.51	1.19	0.46
INDIV	I-II	-				
DAM8	III	9-12	1.31	0.47	0.76	0.43
DAM5	III	9-12	1.99	0.34	0.92	0.40
TEAT8	III	9-12	1.69	0.42	0.99	0.47
WATERBUCKET	IV	9-10	1.74	0.42	0.93	0.39
WATERNIPPLE	IV	9-10	1.62	0.41	0.80	0.35

[1] Abbreviations are explained in Table 1 (page 6).

3.1.2 Dry feed intake

The period from birth to weaning is very challenging in the calf's life. For example, during this transition period the calf must change from using glucose supplied from milk, to using short-chain fatty acids from rumen fermentation as a primary energy source. Unrestricted access to milk or milk replacer may delay calves' development into ruminants if calves are satisfying their nutritional needs from liquid feeds instead of solid ones (Heinrichs and Lesmeister 2005). Therefore, besides milk the calves should be encouraged to eat increasing amounts of dry feed and thus advance their development into ruminants around weaning time. The developing rumen needs concentrates, and forage such as hay, grass or silage, and water. Concentrate feeds favour propionic and butyric acid type of fermentation and promote the development of rumen epithelium i.e. growth of the rumen papillae, the absorptive surface of the rumen. Intake of forage is the primary stimulator of increased rumen volume and development of rumen muscles. Intake of forage also stimulates the flow of saliva into the rumen and keeps the pH in the rumen higher (Stobo et al. 1966, Nocek et al. 1984, Heinrichs and Lesmeister 2005). Increased feed particle size is also important in removing degenerating epithelial cells and preventing parakeratosis, which impairs absorption of VFA from the rumen (Heinrichs and Lesmeister 2005). The increase in relative size of the reticulo-rumen rises from 25-35 % at birth to 62-80 % in the adult (van Soest 1994).

The calves started to eat dry feeds after the fourth live week in all experiments (I-IV, Figures 2 and 3). Hay intake was smaller than concentrate intake and on the average ≤ 0.1 kg DM during the milk feeding period (Table 3) equal to previous experiments (Kossila and Mäntysaari 1992, Hepola et al. 1997, Pursiainen 1997).

Effect of group-rearing

Group-housed calves consumed more hay than individually housed ones (II, 0.07 vs. 0.04 kg/day, P=0.01, Figure 3) during the milk feeding period, in agreement with the study by Phillips (2004) in which the grouped calves ate more grass than individually fed ones. Social facilitation may have increased the roughage intake of group fed calves, as will be discussed later (Chapter 3.3.2). It is also possible that poorer hay consumption of individually housed calves in II was partly due to lesser appetite caused by a higher incidence of diarrhoea (I). Concentrate intake was also numerically higher in groups than in individual pens (II, 0.26 vs. 0.20 kg/day, Figure 2) but this difference was not statistically significant. Richard et al. (1988) and Terré et al. (2006b) also found no difference in starter intake between groups and individual pens, and Chua et al. (2002) no differences in milk, concentrate and hay intakes between individually and pair-housed calves.

Effect of cold rearing

Housing calves in groups either inside or outside the barn (with or without heated shelter), did not have any effect on average concentrate and hay intakes during the milk feeding period (II, Figures 2 and 3). In some studies the calves´ feed intake in cold housing has been higher (McKnight 1978, Kunz and Montandon 1983) than in warm housing. Long-term cold stress may increase calves´ energy requirements for maintenance and increase their feed intake (Young 1981). On the other hand, in II the concentrate and total DM intakes decreased with decreasing temperature during some study weeks. The reason for the decreased concentrate intake was possibly that the calves avoided going from the shelters to outside feeding places at lower temperatures (I, II). The calves received about 70 % of their total DM intake from the whole milk and thus fulfilled the main part of their energy need with milk. With very restricted milk feeding it could be a welfare problem if the calves do not come to the feeding place to eat starter and roughage. Adequate food will ensure that the calf is able to cope with a wide range of temperatures (Phillips 2002).

Effect of milk amount

In general, when milk amount offered increases, intake of solid feed decreases (Williams and Frost 1992). Restrictively milk fed calves (6 l/day, II) started to eat concentrates earlier than calves suckling their dams restrictively (III) or receiving milk ad libitum (IV) (Figure 2). The average concentrate intake of restrictively suckling calves during the first five weeks and *ad libitum* milk replacer fed calves during the entire milk feeding period was small (III, IV, Table 3, Figure 2). One reason for this was probably the high milk intake. The same trend in solid feed intake has been observed in many experiments where milk intake has been high (Härtel et al. 2002, Jasper and Weary 2002, Jensen 2006,

Kristensen et al. 2007, Nielsen et al. 2008a). On the other hand, with more restricted milk feeding (10 % of body weight) calves' concentrate intake during the first month was higher than in II, i.e. 0.25 kg/day at the age of 3-4 weeks (Appleby et al. 2001). Calves in all treatments also ate hay (Figure 3). Calves in IV were bigger than in the other treatments (Chapter 3.2) and quality of hay was also the best in IV (the lowest NDF-content), which could also have had an effect on the hay intake of *ad libitum* milk fed calves (IV). The correlation between fibre content and hay dry matter intake is negative (-0.82) (Kossila and Mäntysaari 1992).

Milk DM intake decreased concentrate and hay DM intakes at the age of 6-8 weeks (meta-analysis, $P<0.01$ for concentrate and $P=0.02$ for hay, Figure 4). The effect of milk intake on concentrate intake was bigger than on hay intake. On the other hand, when looking at *ad libitum* fed calves (IV) the decrease in hay intake with increased milk intake was bigger than in the whole dataset (II-IV). Olsson (1981) did not find any significant relationship between the level of milk feeding and concentrate intake at the age of 0-4 weeks. However, in accordance with the present results concentrate intake decreased when milk intake increased at the age of 5-7 weeks (Olsson 1981). Actually, according to experiments reviewed by Williams and Frost (1992), the calf cannot compensate for the withdrawal of energy supplied from milk with the same amount of energy from dry feed during the first month.

Dry feed intake and weaning

The suggested criteria for adequate dry feed intake before weaning off milk have varied a lot, i.e. from 400 g concentrates for three consecutive days (Leaver and Yarrow 1972) to 1-1.5 kg dry feed /day (Margerison and Downey 2005). The amount of milk given affected the average concentrate intake before weaning (II-IV, Figure 2). In II the calves that received 6 l milk/day ate 650 g concentrates on average during the week before weaning, and in IV the *ad libitum* milk-replacer fed calves half of that amount (300 g/day). The dam reared calves (III) which were weaned at the age of five weeks ate practically no concentrates, and the dam reared calves weaned at the age of eight weeks about 200 g/day. In the same experiment (III) the teat fed calves, which were weaned at the age of eight weeks, ate nearly 600 g /day. Large individual differences existed between the calves. For example, in IV the concentrate intake varied between 67-761 g/day during the last week before weaning. In the recent experiment by Roth et al. (2007) improved weight gain was achieved when using a concentrate-intake-dependent weaning method i.e. reduction of milk allowance according to individual consumption of concentrate.

Dry feed intake after weaning

The intake of dry feeds increased quickly after complete weaning in all experiments (II-IV, Table 5, Figures 2 and 3), as seen in the study of Jasper and Weary (2002). However, the calves which were abruptly weaned at the age of five weeks (III) consumed only 230 g/day of concentrates during the week after the weaning. The concentrate amount then increased, and was on average 1.3 kg/day at the age of eight weeks. Concentrate intake of calves varied between 1-1.5 kg/day on the week after complete weaning in all treatments that were weaned at the age of eight weeks, except for calves which were suckling their dams during eight weeks. However, for dam-reared calves, weaning was not only weaning off milk, but also the complete separation from the dam, and this may have disturbed the calves (III, Hepola et al. 2006, Chapter 3.3.6). Concentrate intake was restricted to 2.5 kg/day in II-III and it took the longest time for dam-reared calves to achieve this amount. There was a positive relationship between concentrate intake three weeks before, and two weeks after weaning (meta-analysis, $P<0.01$, Figure 5). At the age of three months hay intake was highest in group reared calves (II, Figure 3).

After the milk feeding period there was no significant difference in feed intake for groups outside, with, or without heated shelter, or in a heated barn (II). However, calves were eating straw more often in the outside groups than in the inside group (II), possibly because they spent more time inside shelters (I).

To conclude, high amounts of milk decreased concentrate intake before weaning, but concentrate intake increased quickly after milk provision was stopped. Calves were abruptly weaned from high milk amount (IV), which may have contributed to the negative responses of *ad libitum* feeding per se, i.e. low concentrate intake before weaning, and also a setback in growth after weaning and less rumination than restrictively fed calves before weaning, as will be discussed later (Chapters 3.2. and 3.3.4). Gradual weaning reduces many of the distress responses when calves are fed high milk volumes (Khan et al. 2007 a,b, Nielsen et al. 2008a). Also in III, five weeks of twice a day suckling, followed by three weeks of once a day suckling, reduced the decline in energy intake and growth following weaning, compared to abrupt weaning at the age of five weeks. The results (I-IV) and literature presented support the previous suggestions to feed large amounts of milk during the first month and then gradually weaning to solid feed (Hodgson 1971a, de Passillé et al. 2004).

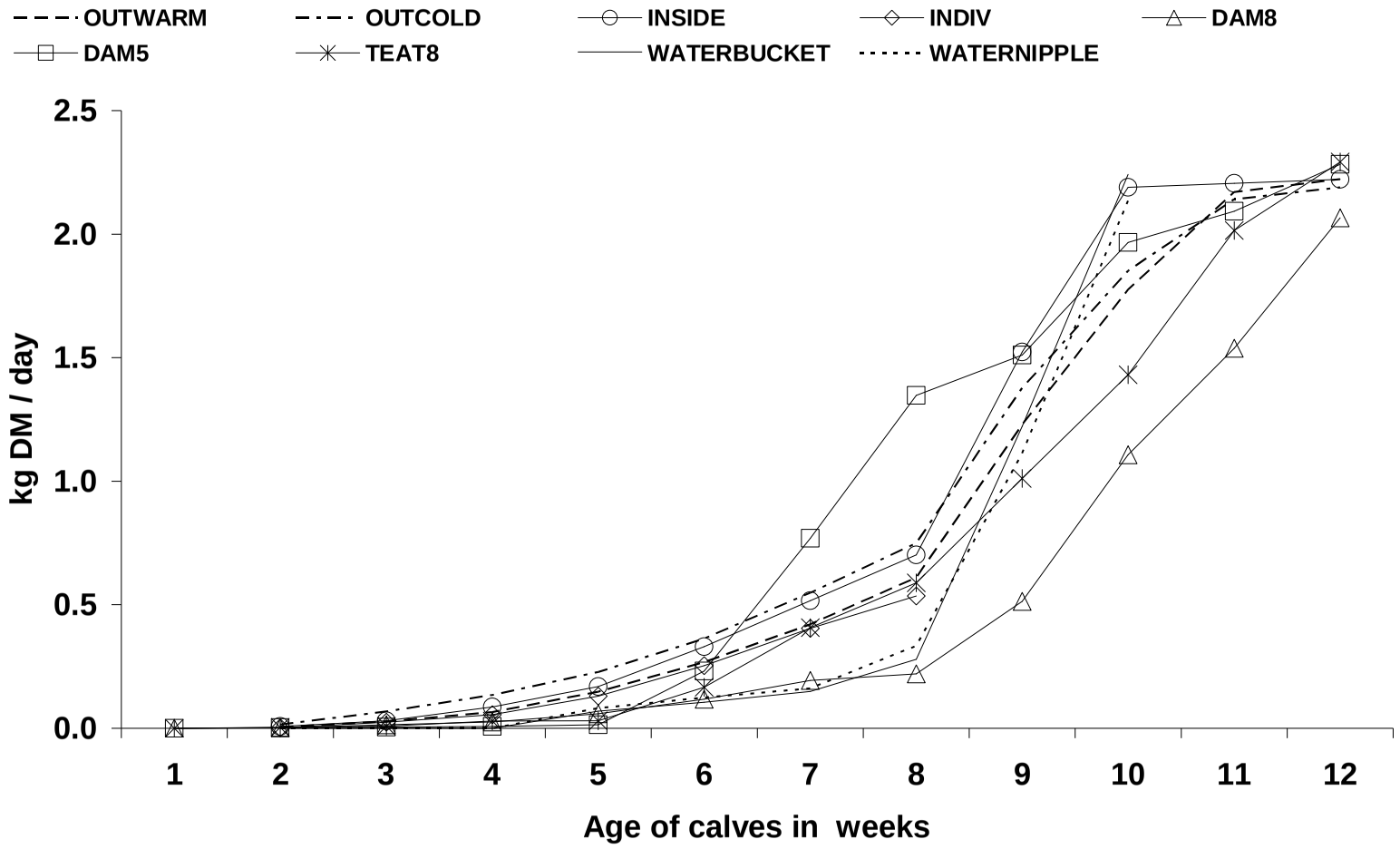

Figure 2. *Concentrate intake of calves, kg DM/day. Treatment abbreviations are explained in Table 1 (page 6).*

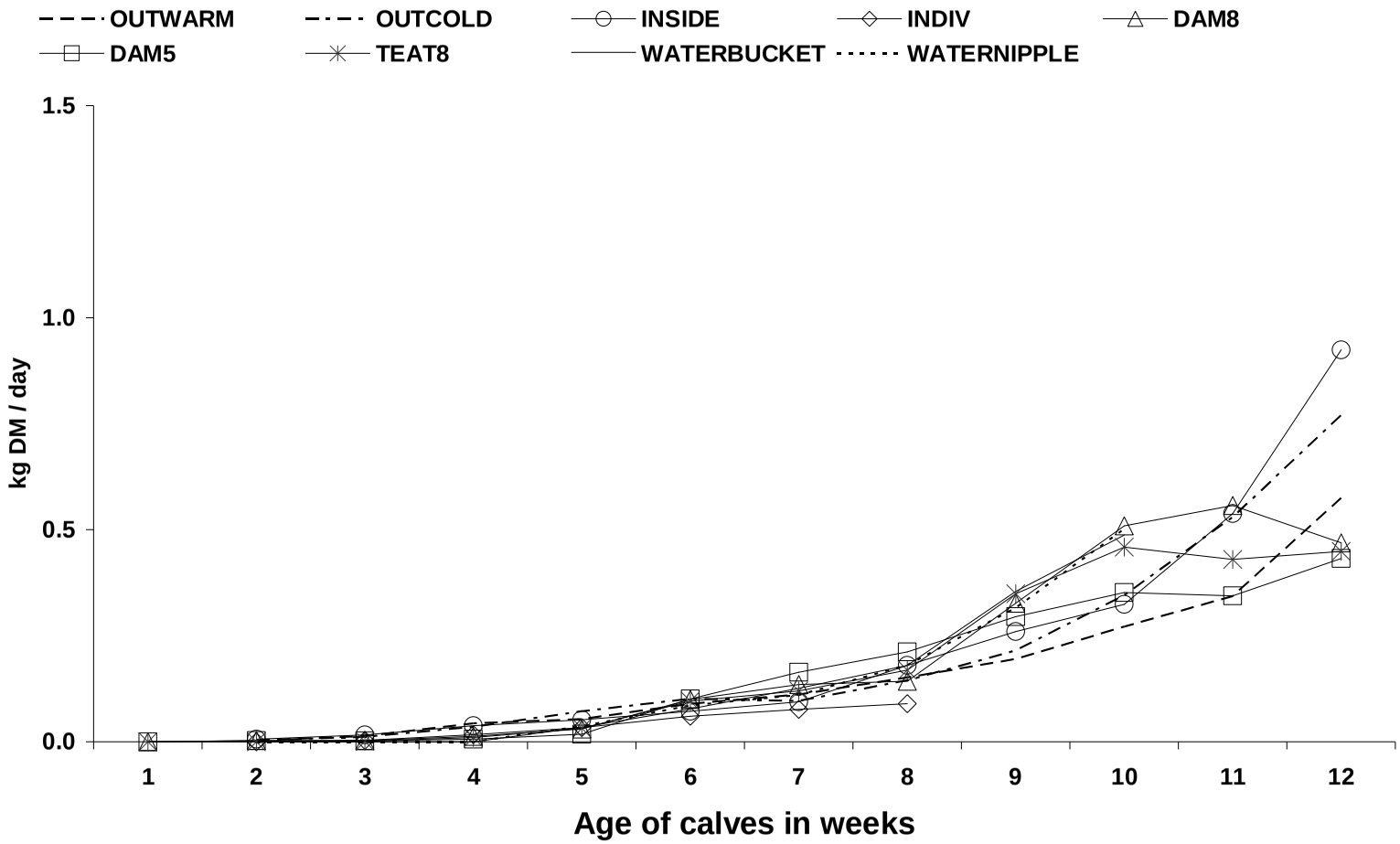

Figure 3. *Hay intake of calves, kg DM/day. Treatment abbreviations are explained in Table 1(page 6).*

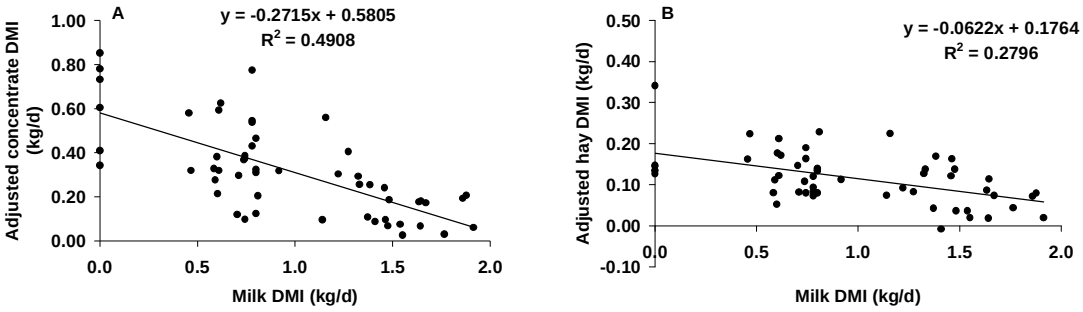

Figure 4. *Relationships between milk dry matter intake (DMI) and adjusted concentrate DMI (A) and adjusted hay DMI (B) of calves at the age of 6-8 weeks (data from II-IV).*

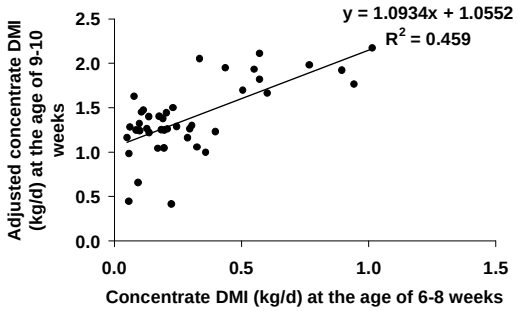

Figure 5. *Relationship between concentrate DM intake of calves at the age of 6-8, and 9-10 weeks (data from III-IV).*

3.1.3 Energy and protein intake

Weekly energy and protein intake data from I-IV are presented in Figures 6 and 7. Hence, it can be seen that complete weaning off milk or diminishing milk intake at the age of five weeks or complete weaning off milk at the age of eight weeks were the points after which energy and protein intakes decreased during the following week. Otherwise both the energy and the protein intakes increased quite linearly in all treatments (Figures 6 and 7). A line for recommended energy and protein intakes (MTT 2006) is drawn for comparison.

Effect of restricted milk intake, and group, and cold rearing

Individually fed calves received a little bit less energy and protein than group fed calves but no differences existed between groups inside or outside. After weaning at the age of eight weeks both energy and protein intakes decreased when nutrition changed. Energy and protein intakes increased more rapidly in the inside group than in outside groups after weaning (Figures 6 and 7).

Finnish feeding recommendations (MTT 2006) for the energy and protein intakes of calves have been calculated for the 400-600 g daily growth during the first live month, and 800-1000 g daily growth during the second and third months. The recommendations describe the average requirement for each month. Restrictively fed calves (I, II) received on average the same amount of energy and protein during the first month compared to the recommendations, but weight gain (700 g/day) was clearly higher than the above mentioned growth target (400-600 g/day). At the age of three months, energy and protein intakes were a little bit lower, but growth higher, than in the recommendations (Figure 8). The present Finnish recommendations have been modified from recommendations from other countries. The genetic level of animals and rearing methods have changed during the years and this may be the reason why our data are not in line with the present recommendations. Although the present data (I-II) is limited the difference between the observed and target growth suggests that there might be a need to re-evaluate feeding recommendations for dairy calves (MTT 2006).

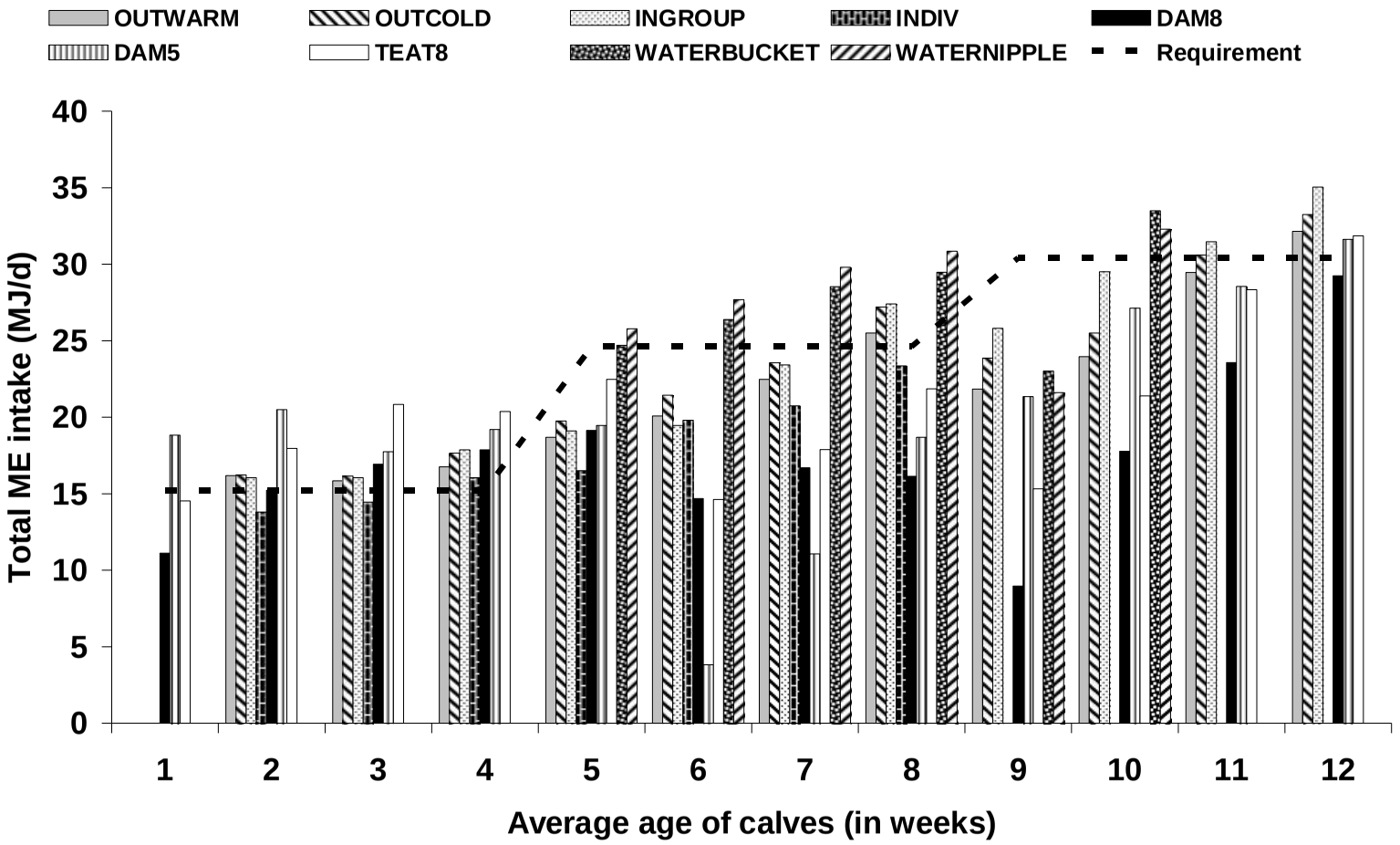

Figure 6. *Total energy intake of calves (MJ ME/day) during the experiments. Treatment abbreviations are explained in Table 1 (page 6).*

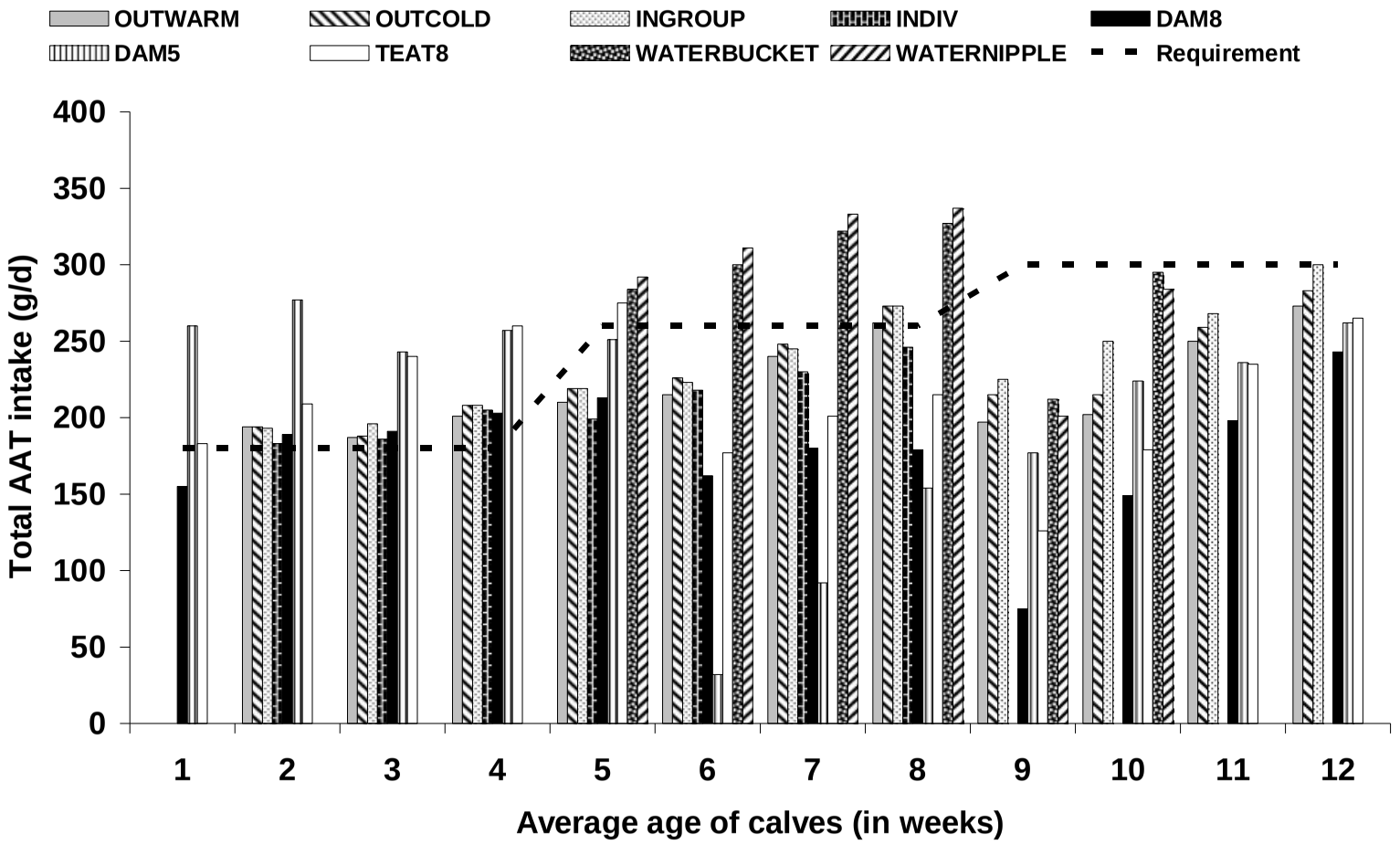

Figure 7. *Total protein intake of calves (g AAT/day) during the experiments. Treatment abbreviations are explained in Table 1 (page 6).*

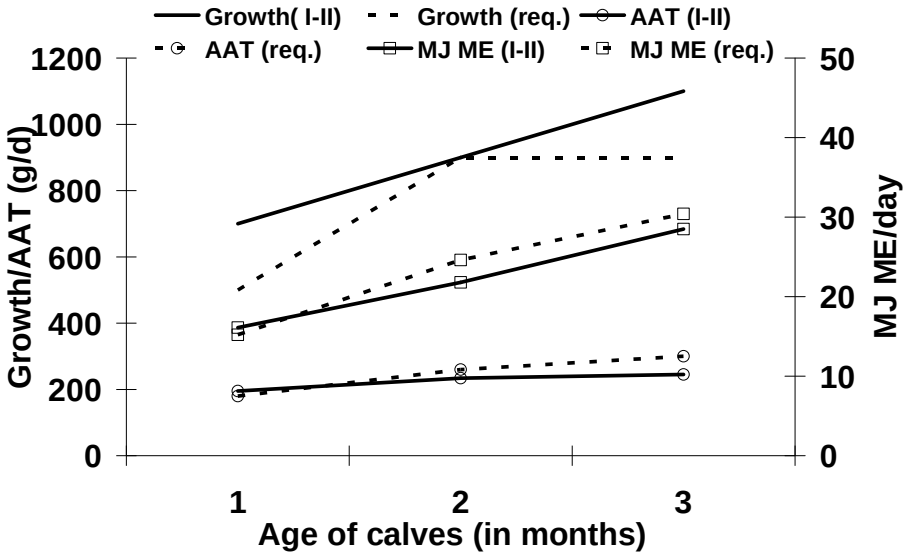

Figure 8. *Energy (MJME) and protein (AAT) intake and growth of calves in I-II compared to the recommendations (MTT 2006).*

Effect of restricted suckling

During the first month restrictively suckled calves received, on average, energy and protein more than calves that were given 6 litres milk per day (Figures 6 and 7). Energy and protein intakes decreased dramatically at the age of five weeks when the calves were completely weaned from restricted suckling. These calves obviously had to use body reserves for energy, because determined free fatty acid (FFA) concentrations in blood increased (Hovinen 2000). Greater inhibition of fat mobilization with higher feeding intensity has been found by Hammon et al. (2002). These young calves evidently had problems in coping with big changes in nutrition. Also, diminishing milk feeding or suckling times from two to one at the age of five weeks induced decreased energy and protein intake during the following weeks. During weeks 6 to 8 the calves in III received less energy and protein on average than calves in II (Figures 6 and 7). When calves were completely weaned at the age of eight weeks, energy and protein intakes dropped again, more with calves which had still been suckling their dams. Weaning for dam-reared calves was also the complete separation from the dam and this may have disturbed the calves (III, Hepola et al. 2006, Chapter 3.3.6). Both energy and protein intakes of these calves increased quickly after weaning, but during two (weaned from teat) to three (weaned from dam) weeks they were lower than the intakes of calves which had been weaned at the age of five weeks (Figures 6 and 7).

Effect of ad libitum milk intake

During the milk feeding period *ad libitum* milk replacer fed calves (IV) received both energy and protein more than calves in II-III (Figures 6 and 7). *Ad libitum* fed calves suffered a decrease in energy and protein intake after weaning at the age of eight weeks but recovered in one week. During the first week after weaning energy intake of *ad libitum* fed calves was a little lower (22.3 MJME) than that of calves which had received 6 litres of milk during the milk feeding period (23.8 MJME). In the study of Huuskonen and Khalili (2008) *ad libitum* fed calves also showed a decrease in energy intake during weaning. Nielsen et al. (2008a) observed, too, that calves that had received a high milk amount during the milk feeding period had a lower energy intake one week after weaning than the calves that had received a lower milk amount. However, it is possible that the *ad libitum* fed calves did not receive all the calculated energy and protein because they had eaten little dry feeds before weaning and may not have been well-developed ruminants. Calves having enhanced feeding had lower nutrient digestibility one week after weaning at the age of five weeks compared with conventionally fed calves (Terré et al. 2007).

Overall, increased milk intake was seen in increased energy and protein intake. Weaning off milk, either at the age of five or eight weeks, induced a decrease in energy and protein intake and the decrease was more prominent at the age of five weeks than at the age of eight weeks. It is important to pay attention to weaning methods so that calves' energy and protein intakes increase steadily as the calves grow older.

3.1.4 Water intake

The water requirement for animals is affected by many factors including environmental temperature, and age, with young animals requiring more water per unit of body size than mature animals (Maynard et al. 1979). Water constitutes 70-75 % of the weight of the calf and during diarrhoea 10-12 % of body weight can be lost as water (NRC 2001).

Ad libitum acidified milk replacer-fed calves (IV) drank only small amounts of water (on average < 0.4 kg per day), quite similar to the results of Richard et al. (1988). The reason for the small intake was most probably the high intake of milk replacer (12.9 kg/day, Chapter 3.1.1). In a previous experiment, restrictively fed calves (600 g milk-replacer in 5 litres of water/day) drank 0.65 kg water per day (Hepola and Nousiainen 1988). In other experiments calves receiving about four litres of milk, or milk-replacer, drank about 1-2 litres of water (Thickett et al. 1981, Kertz et al. 1984, Abe et al. 1999, Thomas et al. 2007). In addition to milk allowance also the milk replacer mixing rate and electrolyte level in milk replacer can affect water intake. Calves drank least when the mixing rate was lowest (Thickett at al. 1981, Wicks et al. 2005) and an increased electrolyte level increased water intake although not significantly (Hepola and Nousiainen 1988). The variation between calves in water intake was great; between 0 and 3 kg/day during the week before weaning (IV). Large individual variations have been

observed in other experiments, too (Thickett et al. 1981, Hepola and Nousiainen 1988). In the study of Richard et al. (1988) *ad libitum* milk replacer fed calves drank more water in groups than in individual pens. Since the calves drank only little water (IV), it is possible that the milk was also drunk for thirst.

After weaning off milk, calves rapidly began to consume 8 to 9 litres of water per day (IV). The post-weaning ratio of water intake to total DM intake was 4 L/ kg DM, which is similar to the results of Quickley et al. (2006). No difference was found between calves receiving water either from water buckets or nipples in water intake before or after weaning (IV).

A positive relationship was found between water and concentrate intake post-weaning (meta-analysis, P=0.05, Figure 9) as seen with restrictively milk fed calves in other studies during the milk feeding period (Kertz et al. 1984, Quickley et al. 2006). In the study of Matintalo (1989) a positive but weak correlation was also found between water and DM intake during the milk feeding period. No relationship between water and hay intake (meta-analysis, P>0.05), or water intake and growth (meta-analysis, P>0.05), was found before or after weaning in IV. There was a significant correlation of both live-weight gain and pellet intake with water intake in the experiment by Thickett et al. (1981) with restricted milk feeding. For each extra litre of water consumed per day, pellet intake increased 0.082 kg and live weight gain 0.056 kg. In that experiment there was also a significant difference in total water intake according to the initial live weight of the calf (Thickett et al. 1981). In a recent experiment (Thomas et al. 2007) calves were given flavoured drinking water. Flavour (vanilla or orange) did not affect the water intake but orange flavour in drinking water increased starter intake of calves. Glucose supplementation did not alter water intake (Osborne et al. 2007).

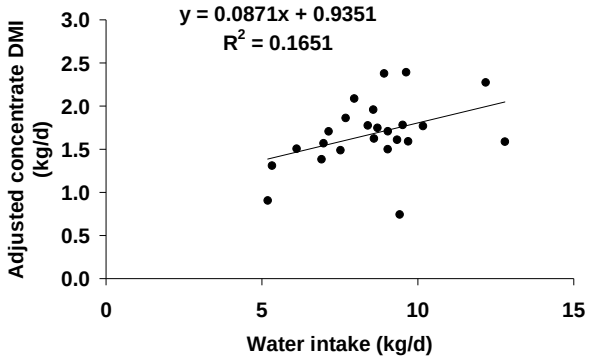

Figure 9. *Relationship between water and concentrate intake of dairy calves at the age of 9 - 10 weeks (data from IV).*

3.2 Growth

Overall, milk intake at the age of 2-5 and 6-8 weeks clearly affected growth (meta-analysis, P<0.01 for both, Figure 10), as also found by Olsson (1981), more at the age of 2-5 weeks than at the age of 6-8 weeks. Milk intake at the age of 6-8 weeks did not affect the average growth rate two weeks after weaning (meta-analysis, P>0.05), in agreement with Olsson (1981). However, growth rates (g/day) varied a lot between different experiments and different weeks (Figure 11).

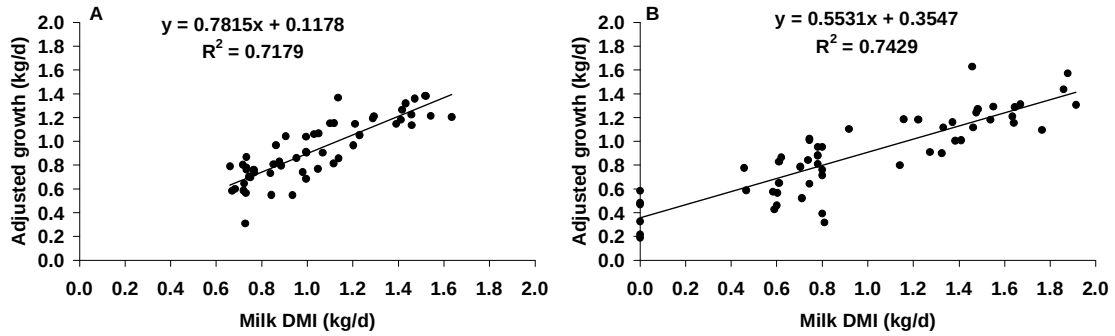

Figure 10. *The relationship between milk DM intake and growth of dairy calves at the age of 2 - 5 (A) and 6-8 (B) weeks (data from I-IV).*

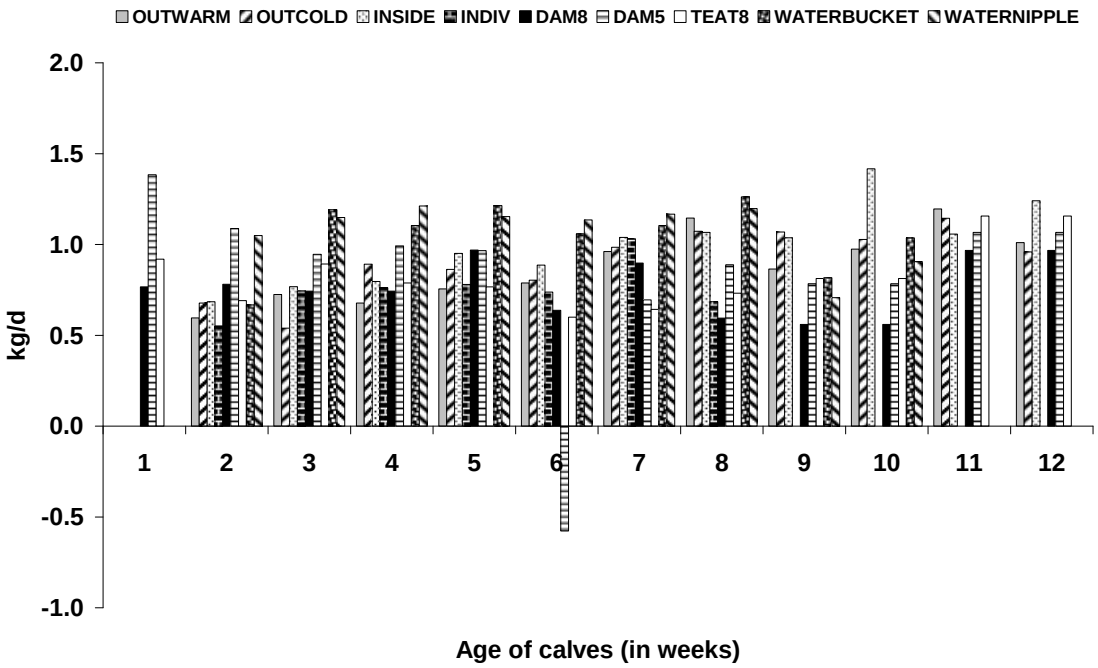

Figure 11. *Average growth rate of calves (kg/d) as the calves grow older. Treatment abbreviations are explained in table 1 (page 6).*

Effect of restricted milk intake, and group, and cold rearing

During the milk feeding period no significant differences were found in average daily growth between individually or group-reared calves (I, Table 3, Figure 11), in agreement with experiments by Warnick et al. (1977), Nocek and Braund (1986), and Terré et al. (2006b). There was a tendency for higher total DM intake in group pen than in individual pens (II) but presumably a part of the higher intake was used for locomotion and not for growth. In some experiments the growth has been higher in individual pens than in groups (Maatje et al. 1993). Calves receiving 6 litres of whole milk during the whole eight week milk-feeding period grew on average 0.76 ± 0.03 kg/day in the individual pens (I, Table 3) which agrees well with the same kind of earlier experiments (Hepola et al. 1997, Pursiainen 1997). In group pens, either inside or outside, growth was on average 0.84 ± 0.04 kg/day (Table 3), as found before (Hepola et al. 1997). Restricted feeding means quite often a milk amount of 8-10 % of body weight. This amount is enough for maintenance plus about 200-300 g daily gain if milk replacer is fed and a little bit more if whole milk is fed. In a cold environment the maintenance cost increases leading to lower growth or the calves may even lose weight (NRC 2001, Drackley 2005). Calves receiving milk amounts of 10 % of body weight and starter grew 0.36 kg/day at the age of 0-2 weeks and 0.58 kg/day at the age of 3-4 weeks in the experiment by Appleby et al. (2001).

The environmental temperature did not affect calves´ weight gain during the milk feeding period (I, II). Controversial results exist of the temperature effects on growth. The daily gain of the calves in cold housing has been the same (e.g. Jorgenson et al. 1970, Webster et al. 1978, Hansen 1984), lower (Scibilia et al. 1987, Scott et al. 1993) or even better (Kauppinen 2000) than in heated buildings. However, after the milk feeding period, the calves kept inside in groups grew better than the calves kept in the outside groups (I, Table 5, Figure 11). Because there was no significant difference in feed intake (II, Chapter 3.1.2) calves outside possibly had to use part of the energy for heat production. In addition, the calves were eating straw more often in the outside groups than in the inside group (II, Chapter 3.1.2). Therefore, straw may have partly increased the amount of rumen contents, which can also mean that part of the live weight gain of outside groups was only rumen fill (Aronen et al. 1994).

Effect of restricted suckling and early weaning

The growth of restrictively suckled calves (III) during weeks 1-5 was a little lower than that observed by Jonasen and Krohn (1991) but higher than that in the study of Fröberg et al. (2005). The differences in growth between experiments are explained most probably by the different milk intakes. Growth was also higher than that of calves receiving 6 litres of milk (I, Figure 11). At the age of five weeks, calves lost weight during the first week after weaning (III, Figure 11). Weaning from high milk amounts at the age of 6-8 weeks has also induced weight loss or at least a reduction in growth rate in other experiments

(Jonasen and Krohn 1991, Bar-Peled et al. 1997). On the other hand, Heinrichs et al. (1990) and Quigley et al. (1991) did not find any difference in growth of earlier (4 weeks) or later (7-8 weeks) weaned calves. Milk intake in their experiments was, however, much less than in the experiments mentioned before.

The growth of calves, whose milk feeding times were reduced from two to one at the age of five weeks, was also lower during weeks 6-8 than during weeks 1-5, but not significantly (III). The growth of eight week dam reared calves was slightly reduced after weaning (energy and protein intakes lower, Chapter 3.1.3) and these calves grew more slowly than the other calves in III after weaning, but this was not statistically significant. On the other hand, it is possible that all significant differences were not revealed because of the small number of animals in this experiment.

Effect of ad libitum milk intake

During the milk feeding period growth rate of *ad libitum* milk replacer fed calves was on average 1.1 kg/day (IV, Table 3, Figure 11). Calves have grown more with increased milk allowance in the other experiments, too (Appleby et al. 2001, Jasper and Weary 2002, Jensen 2006, Huuskonen and Khalili 2008, Nielsen et al. 2008a). *Ad libitum* fed calves in our study grew better than in other studies (Appleby et al. 2001, Jasper and Weary 2002), but the calves consumed high daily portions of milk and the rearing period was also longer. At the age of eight weeks calves lost weight just after weaning but they recovered quickly (IV). Decreased growth after *ad libitum* milk feeding was also seen in the study of Härtel et al. (2002) and Bar-Peled et al. (1997) with calves suckling their dams.

Overall, average growth rate was rather good in all experimental treatments before weaning off milk and the more calves received milk the more they grew before weaning. Abrupt weaning from great amounts of milk at the age of five or eight weeks decreased growth after weaning, probably because the calves were not eating enough concentrates before weaning. At the age of 11 weeks final weight was greatest for *ad libitum* milk replacer fed calves and lowest for eight week dam-reared calves, the average difference being 26 kg (Figure 12). On the other hand, body weight is not necessarily an accurate measure of body weight gain (Owens et al. 1993, Kertz 2007), because differences exist in growth composition (protein/fat), weights of gut fill, and gut tissue mass (Stobo et al. 1966, Roy 1980, Forbes 1995). It has been suggested that wither or hip heights should be measured in addition to the body weight (Kertz and Chester-Jones 2004).

Production (for instance growth) as a measure of welfare is not unequivocal. Growth has been the focus of selection for a long time and it can be manipulated by feeding etc. Poor production performance may be associated with poor welfare but good production is not necessarily a guarantee of good welfare (Keeling and Jensen 2005). Drops in productivity can provide information about animal welfare but this analysis should be carried out at

the individual level and not at the group level as reviewed by Rushen and de Passillé (1998) and Anon. (2001). Good growth can also be achieved by extensive behavioural and physiological coping procedures. Each animal has several alternative methods for coping and individuals can use different methods (Fraser and Broom 1990).

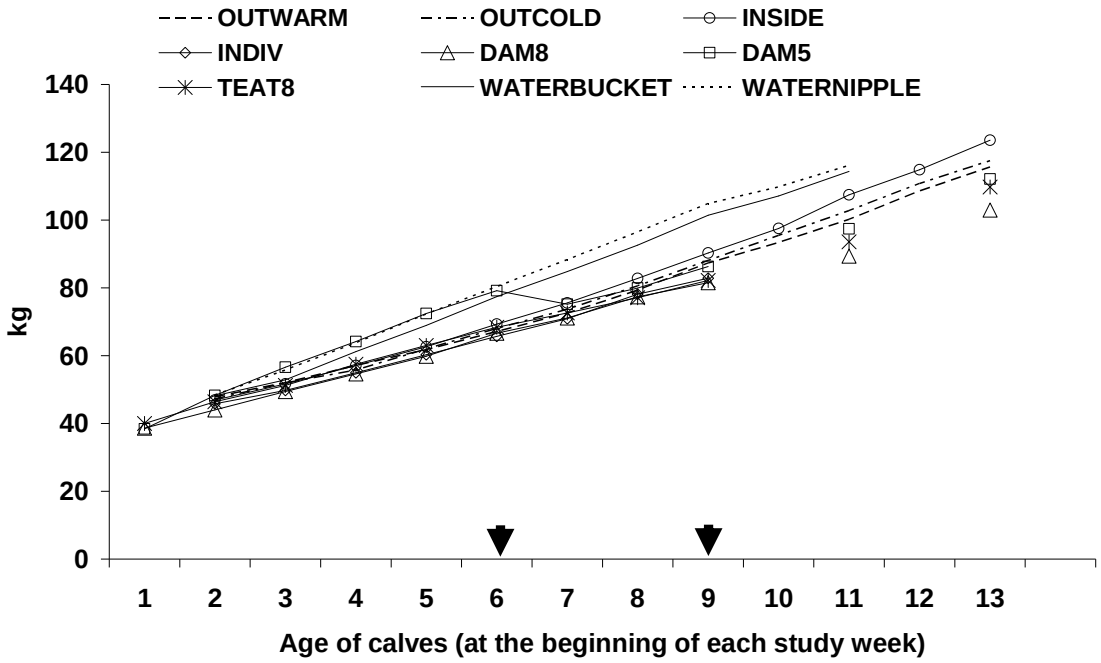

Figure 12. *Average live weight of calves as the calves grow older. Treatment abbreviations are explained in Table 1 (page 6). Black arrows mean weaning time.*

Feed efficiency

Feed efficiency (kg growth/kg DM) was generally better before weaning than after weaning (II-IV, Tables 4 and 5) as in recent experiments (Khan et al. 2007 a,b). Dry matter intake after weaning increases, but growth rate does not increase in the same ratio. Feed efficiency expressed as kg growth /MJ ME was also higher before weaning than after weaning (III, IV). Concentrates and hay have a lower ME content in DM than milk (MTT 2006). In addition to lower energy content, the efficiency of utilization of metabolizable energy for growth is lower for starter feeds and hay than for milk and milk replacer (ARC 1980). Comparison of the feed efficiency between various experiments is

difficult because feeds and also rearing periods are different. Generally, the calculation of feed efficiency for small calves is not easy. Variation in starter intake and daily gain with calves is high, and greater before than after weaning (Kertz and Chester-Jones 2004), and accurate measurement of body weight gain is not easy as already discussed (Chapter 3.2).

It seemed that the suckling calves used energy more efficiently for their growth than the teat fed calves in the same experiment (III, Table 3). Also the suckling calves (III) on average seemed to use dry matter more efficiently during the two first months than restrictively fed calves (II, Table 3). Nevertheless, the exact composition of suckled milk was not known because milk samples were taken from the milked milk as discussed in III. Thus, it is possible that the suckling calves received more fat and energy in milk than calculated, and the actual advantage in feed efficiency could be thus smaller than the one calculated.

It is not possible to compare feed efficiency of the restrictively fed calves (II) to that of the *ad libitum* fed calves (IV), as such, because dry feed intake was not measured during the first month of *ad libitum* fed calves (IV, Table 3). Feed efficiency is usually better when intake, and subsequently growth, increases. In this case dilution of maintenance cost is higher (Davis and Drackley 1998, Diaz et al. 2001, Brown et al. 2005). After weaning off from *ad libitum* milk (IV), the feed efficiency was lower than with restricted milk feeding (II, Table 5). This may imply that the calves abruptly weaned from a high milk allowance were not as prepared for the weaning as restrictively fed calves. On the other hand, feed intake and growth of calves in IV was measured only during two weeks after weaning compared to four weeks in II.

3.3 Oral behaviour

The advantage of behavioural indicators of welfare is that the behaviour is often the first reaction of the animal to adapt in the environment (Keeling and Jensen 2005). Changes in the frequencies of behaviours or suppression of behaviour can provide cues about welfare problems (Mench and Mason 1997). Stereotypies are shown in situations in which the animal lacks control of its environment e.g. in those which are frustrating, threatening or severely lacking in stimulation, and it is possible that some stereotypies help individuals to cope with their environment (Broom 1991).

3.3.1 Sucking milk

Sucking motivation is stimulated by milk intake, especially by lactose in the milk (de Passillé et al. 1992, de Passillé and Rushen 2006b). It is reduced more by performance of the behaviour than by milk intake (de Passillé and Rushen 1997). Sucking motivation lasts about 10 min after milk ingestion (de Passillé et al. 1992) and most non nutritive

sucking is seen during that time period (de Passillé et al. 1992, Hepola et al. 1999). On the other hand, the orifice size of the teat affects the time the calves use for nutritive and non-nutritive sucking. When a teat orifice decreased, nutritive sucking increased, and non-nutritive sucking of the empty teat decreased (Haley et al. 1998). In addition, sucking has effects on the physiology of the calf. Insulin and CCK concentrations in blood were higher when calves were allowed to suck the dry teat after the meal and this may affect digestion of food and satiety (de Passillé et al. 1993). Also, the increase of oxytocin was found to be significantly greater during sucking than during bucket feeding. Thus, sucking may enhance growth and have anti-stress effects (Lupoli et al. 2001). Milk drinking duration from open buckets is usually shorter than that from teat buckets or when sucking the dam (Jensen and Budde 2006, Hänninen et al. 2007). However, old calves can drink milk quite quickly also through teats: 2 litres in less than one minute at the age of eight weeks (Hepola et al. 1996, Pursiainen 1997, Hepola et al. 1999). On the other hand, when calves are drinking through teats they have the possibility to satisfy their sucking motivation by sucking the empty teat after milk ingestion. When calves are drinking milk from open buckets they have no possibility to suck, which may reduce welfare of the calves. The lack of opportunity to suck milk also leads to cross-sucking, which is also detrimental to welfare (Jensen 2003, de Passillé and Rushen 2006a).

Restrictively teat fed calves (II) sucked on average 29 minutes per day or about 9.6 min/milk meal during the whole milk feeding period. Part of that time was non-nutritive sucking of the empty teat but it was not recorded separately in this experiment. However, similar teat buckets were used in previous experiment for calves (Hepola et al. 1996, Hepola et al. 1999). In that experiment nutritive and non nutritive sucking times were 2.4 min and 6.2 min per meal at the age of 2-3 weeks, and 1.2 and 6.0 min per meal at the age of 6-7 weeks, respectively. Sucking duration per day did not differ between individually and group reared calves (II) as also found by Chua et al. (2002) in individually and pair housed calves. In groups the calves were tethered during the milk feeding time (II) and there was no competition for teats. Reduced access to teats may increase competition and decrease feeding time by group-housed calves (von Keyserlingk et al. 2004).

During the whole restrictive suckling period (8 weeks) the average nursing time was 20 min per meal, thus during the first five weeks of age 40 min per day (2*20 min) and 20 min per day at the age of 6-8 weeks (III). The actual time spent sucking was lower than the nursing time as one nursing bout included breaks of less than one minute between suckling bouts. The calves sucked for 13.2 min (±1.23) per meal at the age of 1-5 weeks and 14.7 min (±1.53) per meal at the age of 6-8 weeks on average (III), a little longer than Fröberg et al. (2005) observed. Hence, the calves used more time sucking per meal their dams than teat buckets (II). This finding was similar to the recent study by Hänninen et al. (2007) where it took more time for two day old calves to suck colostrum from dam than from teat or open bucket. Sucking time/meal remained quite similar during the whole suckling period (III). Decreasing the milk amount in the udder has been shown to increase sucking time (de Passillé and Rushen 2006c). However, reducing

suckling from twice a day to once a day at the age of five weeks (III) made the calves change teats during suckling more often (51 times ± 6.3 and 94 times ± 8.8, respectively). This was maybe because the calves were given milk only in the morning and they most probably were hungry and their feeding motivation was high. When the calves started to get milk only once per day they were not yet eating much concentrates (III). Increase in teat changing of hungry calves was also observed by de Passillé and Rushen (2006c).

Ad libitum fed calves (IV) had on average 11±1.7 milk drinking bouts per day at the age of two months which corresponds to Appleby et al. (2001) at the age of one month and suckling times of newborn calves with their dams (Hänninen et al. 2007). The length of a milk sucking bout was 5 ± 0.7 min which is less than in the recent study of two day old calves (Hänninen et al. 2007). Milk drinking time was found to decrease as calves grow older (Hepola et al. 1996, 1999). The average total milk drinking time per day, 30 ± 3 min was less than that found by Appleby et al. (2001) but the same as with restrictively fed calves (II). In the *ad libitum* system the calves have no possibility for non- nutritive sucking which can increase the milk amount sucked (Chapter 3.1.1, Hammell et al. 1988).

3.3.2 Eating dry feeds

Increased time for concentrate and hay intake was seen as the calves grew older (II and IV) as also presented earlier (Hepola et al. 1997). Eating times increased rapidly after weaning (IV, Figures 13 and 14) as did intake amount in kilograms (Chapter 3.1.2).

Group-housed calves started to eat hay at an earlier age (Figure 14) and also consumed more hay than individually housed ones (Chapter 3.1.2). Group-housed calves also ate concentrates on average more often than individually reared calves (II, Figure 13). Increased hay intake and the longer time spent eating concentrates during the first weeks of life may be due to social facilitation. Other authors have also reported earlier intakes of concentrates (Warnick et al. 1977) and longer time spent eating grass or solid feeds for the grouped than individually fed calves (Babu et al. 2004, Phillips 2004). On the other hand, time spent feeding was not affected by group size in the study of Færevik et al. (2007). Phillips (2004) suggested that the sight of feed serves as a stimulus for social facilitation to synchronize eating behaviour. In that experiment the calves could see the other calves eating grass but not when they ate concentrates from buckets. In II the calves ate from common feeding troughs and could see if other calves were eating either hay or concentrates.

At two months of age the calves used on average 46 and 23 min /day for eating concentrates and 84 and 86 min /day for eating hay in II and IV, respectively (Figures 13 and 14). In a similar experiment as II (Hepola et al. 1997) the duration of eating hay was in accordance with results presented here and the duration of concentrate eating was 35 min/day on average. Thus, in spite of the high amount of milk (IV) calves ate also hay,

although with *ad libitum* milk feeding hay intake was decreased with increased milk intake (Chapter 3.1.2). If calves have no or only minor possibility to eat roughage it can also be a welfare question. Eating time for concentrate is short and it has been shown using calves (Kooijman et al. 1991) and adult cattle (Sambraus 1985, Redbo and Nordblad 1997) that restricted allowance of roughage increases the frequency of oral stereotypies (Chapter 3.3.5). Giving grass to milk and concentrate fed calves reduced the frequency of calves licking their buckets and their pen, vocalizing, and investigating the pen (Phillips 2004). In the EU the calves over two weeks old must be provided with fibrous food, a minimum of 50 g, at the age of eight weeks (Commission Decision 97/182/EC).

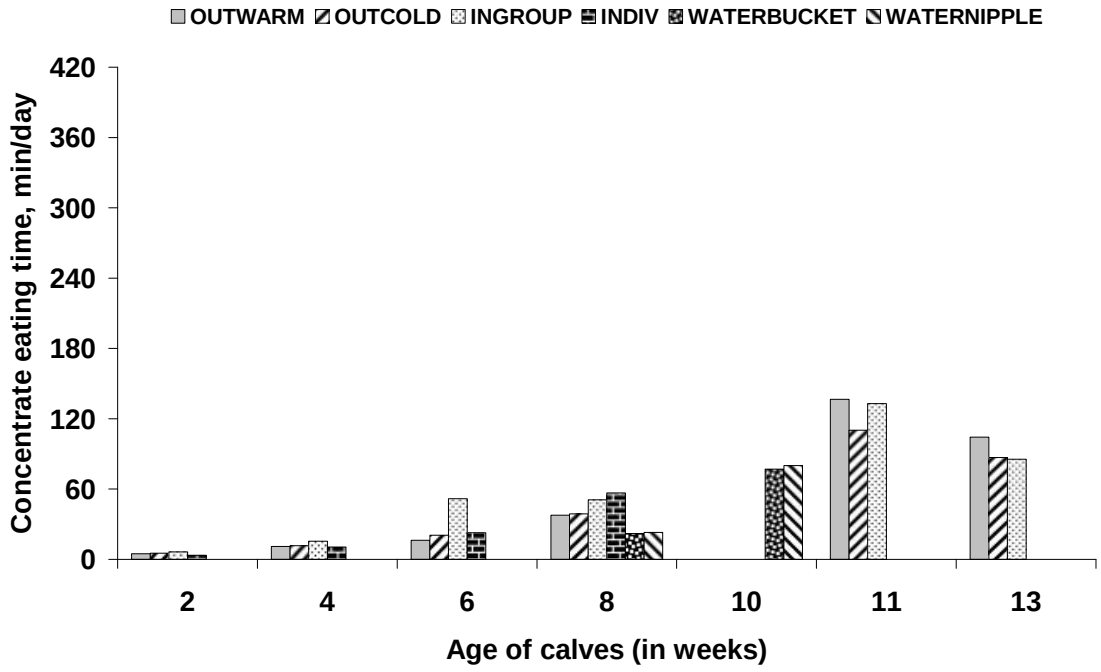

Figure 13. *Concentrate eating time of calves as the calves grow older (II,IV). Treatment abbreviations are explained in Table 1 (page 6)*

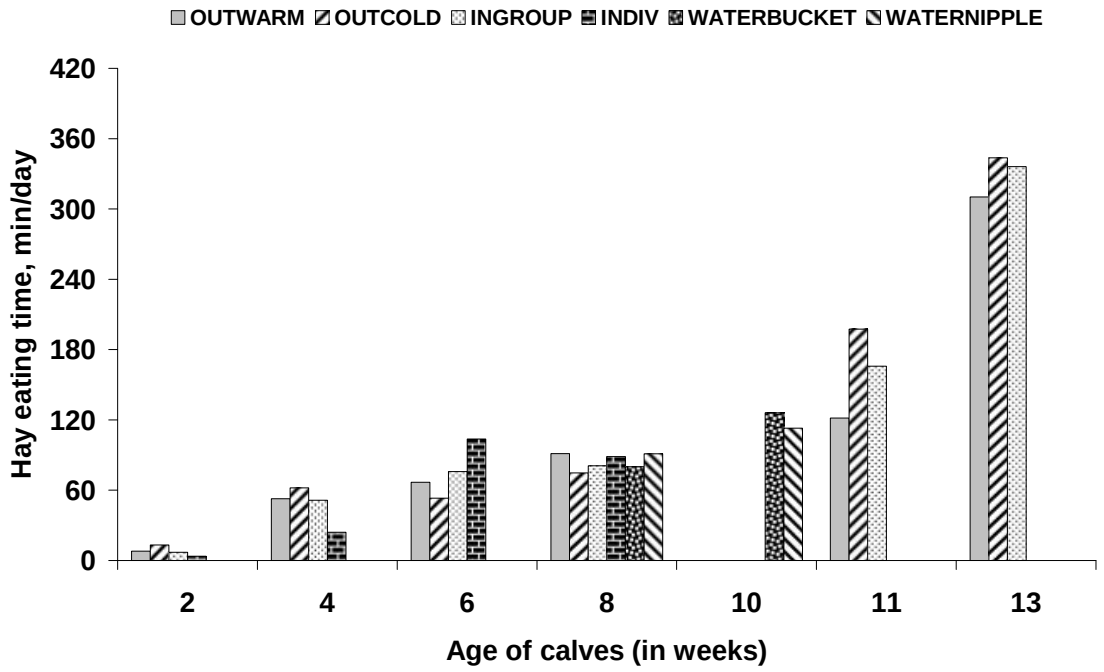

Figure 14. *Hay eating time of calves as the calves grow older (II ,IV). Treatment abbreviations are explained in Table 1 (page 6).*

3.3.3 Drinking water

Calves drank water more frequently from nipples than from buckets (Figure 15), although the lengths of water-drinking bouts were similar from both water sources (IV). Thus, the total daily duration spent drinking water was longer from nipples than from buckets (IV). Because there was no difference in water intake (Chapter 3.1.4), calves received less water during one drinking bout from a nipple than from a bucket. In addition, 75% of their drinking bouts were performed in unusual ways, such as by pressing the water nipple with their forehead and drinking the dripping water. According to these results, it is suggested that the water nipples may be difficult or inconvenient for calves to use. Adult cows prefer drinking from a water trough instead of a stream (Sheffield et al. 1997), and from larger troughs instead of smaller ones (Machado et al. 2004, Teixeira et al. 2006). When veal calves were provided with water, no effects on productive traits were observed compared to calves which did not receive water. However, when water was available, the calves drank it, and positive effects were noticed on their non-nutritive oral behaviours and chronic stress indicators (Gottardo et al. 2002).

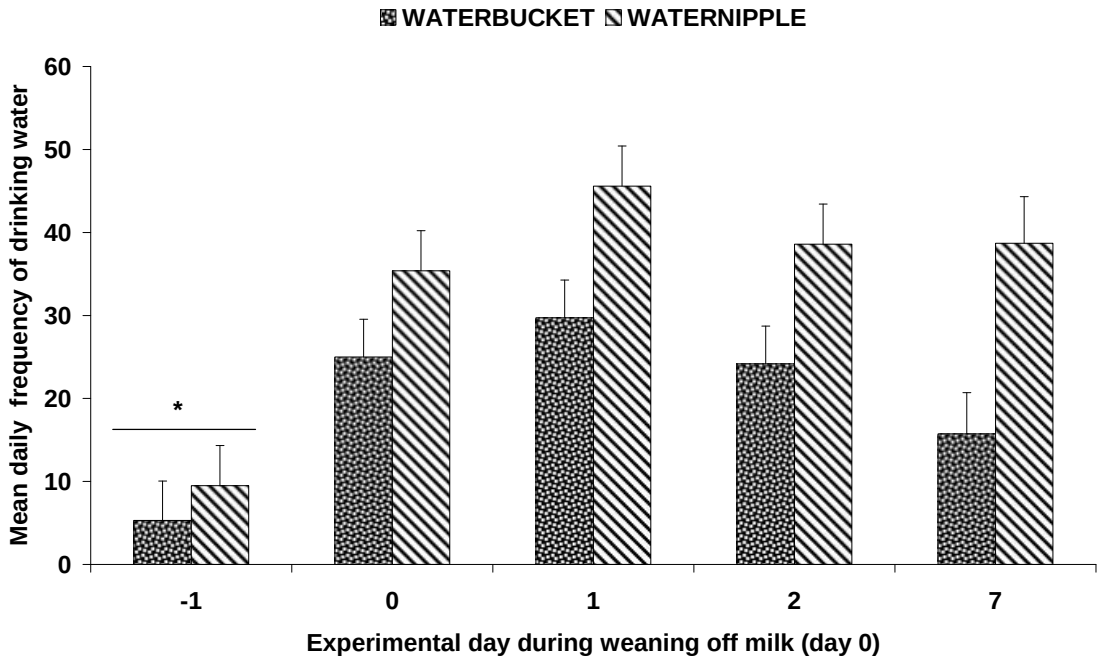

Figure 15. *Mean daily number of water drinking bouts of calves from open water buckets or from water nipples (IV). Treatment abbreviations are explained in Table 1 (page 6).*

3.3.4 Ruminating

Rumination time increased as the calves grew older (Figure 16) as also reported earlier (Swanson and Harris Jr. 1958, Hepola et al.1997, Margerison et al. 2003). At the age of three months calves ruminated about 6 h 30 min (II). This corresponds to 6-8 hours of rumination time in adult cows (Phillips 2002).

As was previously described, the calves started to eat dry feed earlier (Chapter 3.3.2) and ate more hay (Chapter 3.1.2) in groups than in individual pens. This was possibly the reason for group-housed calves starting to ruminate at an earlier age (Figure 16), and ruminating for a longer time, than calves in individual pens (II, Figure 16), as also found by Babu et al. (2004) and Phillips (2004).

Rumination times in II and IV are presented in Figure 16. Restrictively fed calves (6 litres whole milk/day, II) ruminated before weaning 21.7 % of the observation time. Thus, the two month old calves ruminated approximately 5 h /day, similar to the study by Swanson and Harris (1958). Observations were not made between midnight and 6 a.m. so this approximation time may be a bit too short (II). Duration of rumination was 5 h 50 min/day in previous experiments with the same kind of feeding when behaviour was observed 24 h/day (Hepola et al. 1997, Pursiainen et al. 1998). In *ad libitum* feeding (IV) the calves ruminated less, only about 3 h just before weaning. The reason for this difference was obviously the small intake of dry feed before weaning. This may indicate that the *ad libitum* fed calves were not as well-developed ruminants as the restricted-fed

calves by the time of weaning. Rumination time increased after weaning with the increasing dry feed intake in both experiments (II, IV) but it was generally at a lower level in ad libitum fed calves (4 h at the age of 10 weeks) than with restrictively fed calves (6 h at the age of 11 weeks). Quality of dry feed also has an effect on the ruminating time. About 12 week- old- calves, receiving dried long grass as an only dry feed, ruminated about 7.5 hours in the experiment by Hodgson (1971 b,c). Calves in the same experiment receiving pelleted grass ruminated only about 2 hours.

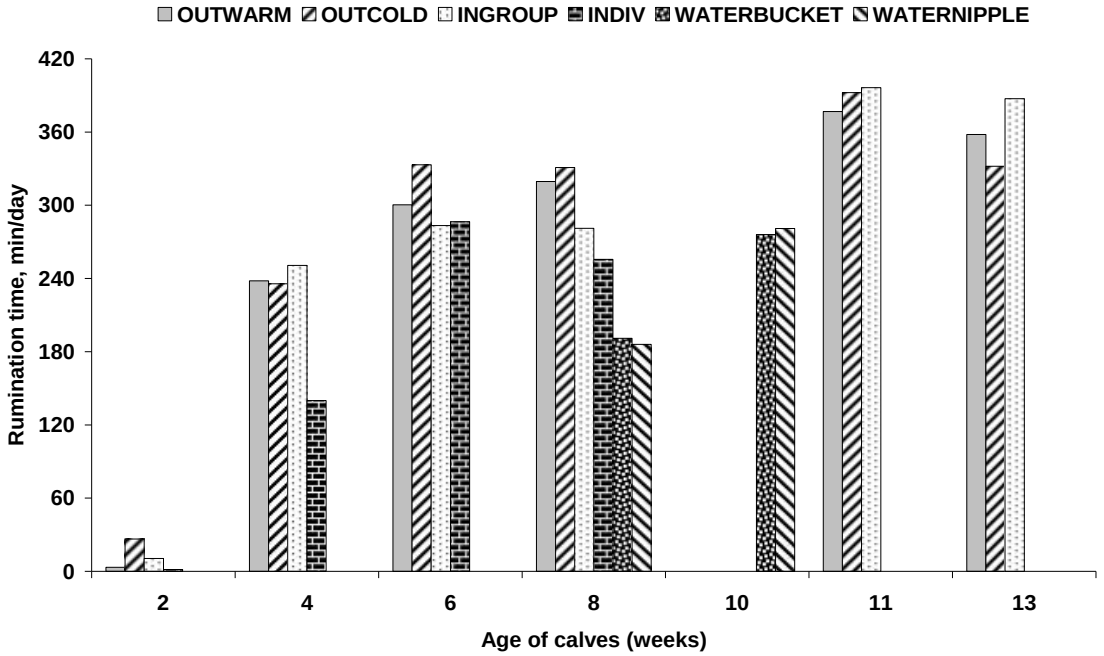

Figure 16. *Rumination time of calves as the calves grow older (II ,IV). Treatment abbreviations are explained in Table 1 (page 6).*

3.3.5 Cross-sucking and tongue rolling

Sucking is induced by the milk ingestion (de Passillé et al. 1992) as discussed in Chapter 3.3.1. Cross-sucking is defined as non-nutritive sucking directed to another calf (Jensen 2003), and considered as abnormal behaviour. Cross-sucking is not seen when the calves are fed by their dams (Lidfors et al. 1994). Cross-sucking is also seen more in bucket fed calves than in teat-fed calves (Jensen and Budde 2006). It is usually related to milk feeding, and disappears after the milk feeding period (Lidfors 1993). Cross-sucking may cause inflammation of the sucked body part and hair loss as referred to by Lidfors (1993) and Jensen (2003). This behaviour may also lead to an inter-sucking which means that heifers or cows are sucking each other (Keil et al. 2000, Keil and Langhans 2001, Lidfors and Isberg 2003).

Cross-sucking in groups was not a problem in II as the calves sucked each other only occasionally (less than 0.5 % of all observations). Cross-sucking was obviously prevented with teat feeding and with the tying-up method (I,II) during milk feeding time, as the sucking motivation is more pronounced just after the milk-feeding (de Passillé et al. 1992, Lidfors 1993). In addition, the calves had free access to concentrate and hay, which are other ways to control cross-sucking problems (Wood et al. 1967, Haley et al. 1998). The provision of hay immediately after the milk meal may be effective in reducing non-nutritive sucking, especially when calves are provided with limited amounts of roughage (Haley et al. 1998).

However, cross-sucking was more frequently observed with the *ad libitum* milk fed calves (IV) than in II when calves were in the yard with another calf for two hours in the morning (1.2 % of observations before weaning). The level of cross-sucking was about the same as with teat fed calves in the experiment by Nielsen et al. (2008b) one week before weaning. Cross-sucking increased significantly after abrupt weaning (10 % of observations). Seven calves out of 22 cross-sucked before weaning and 15 after weaning, with 95 % of cross-suckings being under the belly. The reason for this increase could be hunger, as suggested by Jensen (2003). Gradual weaning during 14 days reduced cross-sucking immediately after weaning compared to abrupt weaning in the study by Nielsen et al. (2008a). Nutritional undersupply during weaning can promote cross-sucking (Keil and Langhans 2001, Roth et al. 2007). Cross-sucking was reduced by using a concentrate-intake-dependent weaning method in the experiment by Roth et al. (2007).

Stereotypic tongue rolling occurred very seldom with the restrictively fed calves (II), possibly due to free access to solid feeds (Redbo and Nordblad 1997) and the satisfaction of the sucking motivation. Veal calves which are deprived of solid feed develop tongue rolling (Webster 1984).

However, tongue rolling was observed with *ad libitum* fed calves (IV) when they were in the yard in the morning. Twelve calves out of 22 performed tongue rolling before and eight of them still continued the behaviour after weaning. Calves were possibly frustrated when they had no possibility to eat in the yard. The calves were in the yard in the morning when eating time usually increases (Phillips 2002) and frustration can induce stereotypies like tongue playing (Sato et al. 1994).

Cross sucking and tongue rolling was probably partly stimulated by the environment in the yard (IV). Calves also had a considerable amount of other oral behaviours (around 20%), such as licking structures or other calf during the two hours daily in the yard. In addition to deprivation of feed, other possible explanations are such as exploration of the freshly littered yard and only a restricted possibility for social contact during the rest of the day.

3.3.6 Vocalization

In *ad libitum* fed calves (IV) vocalization increased significantly on the first day after weaning (Figure 17), probably because the calves were hungry (Thomas et al. 2001), but decreased rapidly when the calves started to consume dry feeds. On the other hand, calves could also vocalize more to show frustration with unfamiliar feed i.e. absence of milk. In addition, the calves can also react to the separation from the milk feeding system. Acute response to weaning could be reduced with continued access to the milk-feeding system but with warm water instead of milk (Jasper et al. 2008). However, overall, vocalization was at a much lower level than with calves weaned from dams after five or eight weeks of restricted suckling (III, Hepola et al. 2006, Figure 17). Right after weaning, these calves vocalized more, spent less time lying, and changed from one activity to another more often than before separation These indices of restlessness were not seen when the calves were changed from twice a day suckling to once a day suckling at the age of five weeks (Figure 17). However, for the dam-reared calves, weaning combined both the stressor of social separation and a change in diet. Two stage weaning, i.e. preventing calves or lambs from nursing their dam for some period before their separation, has decreased vocalization compared to abrupt separation in calves and lambs (Haley et al. 2005, Schichowski et al. 2008) or in foster cows (Loberg et al. 2007).

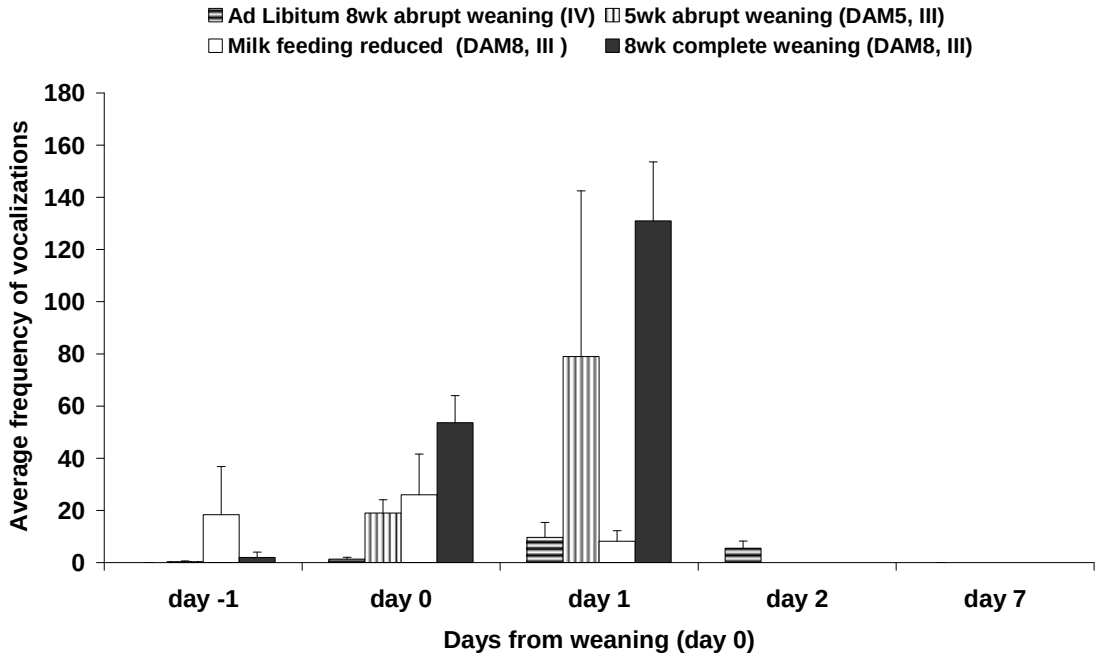

Figure 17. *Average frequency of vocalizations of calves during weaning in experiment 2 (Hepola et al. 2006) and in IV.*

4. Concluding remarks and practical applications of the results

1. Group housed calves can cope with the changing temperatures and in an unheated production system if they are under careful management. However, low temperatures can decrease the time spent eating, and may thus affect growth, at least if the eating place is outside and separated from the lying area, which is in shelter. A cold environment may also increase the risk of diarrhoea.

2. Group rearing may socially facilitate calves to start eating and ruminating earlier than individual housing. Cross sucking in groups of calves can be reduced by feeding and management factors.

3. In restricted suckling, the calves learned fairly easily to suck their dams and were well accepted by the cows but the problem of poor milk let-down existed in some cows during milking. Total weaning of calves at the age of five weeks from a high milk allowance should be avoided because the calves do not eat dry feed in sufficient amounts to compensate for the loss of milk provision and they can lose weight. Calves had problems in coping which could reduce their welfare. Five weeks of twice a day suckling followed by three weeks of once a day suckling reduced the decline in energy intake and growth following weaning.

4. Water intake of *ad libitum* milk replacer fed calves was scarce, either from an open bucket, or from a nipple but increased rapidly after weaning. The variation in water intake between calves was large and therefore it is important that water is available all the time, even with the *ad libitum* milk feeding. The calves had some difficulties in using water nipples, which was seen as atypical ways to use water nipples. Thus, the water nipples may be difficult or inconvenient for calves to use. A positive relationship was found between water and concentrate intake after weaning.

5. Meta-analysis indicated that milk intake affected clearly the growth rate of calves, more at the age of 2-5 than 6-8 weeks. Concentrate and hay intakes decreased by increased milk intake during the final part of the milk feeding period but there was a positive relationship in concentrate intake before and after weaning. Weaning off milk, either at the age of five or eight weeks, induced a decrease in energy and protein intake and the decrease was more prominent at the age of five weeks than at the age of eight weeks. As an *ad libitum* milk allowance clearly reduces the calves' consumption of dry feeds and may increase hunger at weaning, their milk allowance should be restricted before weaning to stimulate the calves' dry feed intake. Hence, it is important to pay attention to weaning methods so that calves' energy and protein intakes increase steadily as calves grow older.

6. According to the present data there might be a need to re-evaluate feeding recommendations for energy and protein for dairy calves (MTT 2006) because there was a difference between the observed and target growths. It is also worth considering whether the growth target for the first month should be increased.

7. Results from feed intake and growth data do not always reveal the differences in rearing systems for dairy calves, in terms of calf welfare, as was seen in these experiments. Behaviour should also be taken into account when comparing rearing strategies for young calves.

Further research

1. This study was carried out with *ad libitum* milk feeding and water intake was scarce. Therefore, more research is needed on the use of water nipples for calves, before and after weaning with restricted milk intake. In addition, more research is needed on the effect of pre-experience of using different water sources (i.e. water nipple or bucket) on water drinking behaviour after weaning.

2. On the basis of this study it was suggested that if calves have an access to an outside exercise yard, it would be better to feed calves inside if the weather is cold or windy. However, more experimental data are needed.

3. Re-evaluation of Finnish feeding recommendations for energy and protein for dairy calves should be considered.

4. There is lack of recent comparative studies on different feeding regimes in current rearing conditions in Finland. Especially research on combination of whole milk and commercial starter vs. commercial milk replacer and home made concentrate would be useful.

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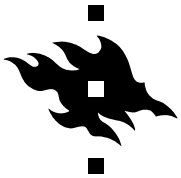

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